MINISTRY OF WATER AND IRRIGATION

Water Resource Policy Support

IMPACT OF INCREASING SUPPLIES OF RECYCLED WATER ON CROPS, SOILS AND IRRIGATION MANAGEMENT IN THE JORDAN VALLEY

TECHNICAL REPORT

By

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EXECUTIVE SUMMARY

Some of the anticipated increase in volume of treated effluent in the Amman-Zarqa basin (ARD, 2000), could be used in the Jordan Valley. This document reports on the examination of the potential impacts on the soils and crops of the Jordan Valley from using increased proportions of King Talal Reservoir (KTR) water without blending.

The overall conclusion is that irrigated agriculture can sustainably produce a wide variety of crops in the Jordan Valley using the quality of recycled water that is available from KTR. The restrictions on crops, primarly due to the salt and chloride levels, will require good management to be productive and prevent salinization of the soils. However, given poor management, any damage done can, in most cases, be reversed.

Because of increased supply, the situation in the Middle and Kherama Directorates may in fact improve due to increased leaching and further intensification of cropping patterns. However, in the Northern Directorate, where the better quality water from KAC is presently used, the introduction of KTR water, would have a significant negative effect on the relatively salt and chloride sensitive citrus-dominated cropping patterns.

Chloride can be detrimental to sensitive trees (e.g. citrus and stone fruits) and grapes, but other toxic ions such as Na and B are not likely to be problematic. It is unlikely that reuse will result in soil infiltration problems but will cause maintenance problems, before and after the farm gate. Although recycled water contains high levels of N and P, which can be viewed as a nutrient resource for the plant, these two, particularly the later, are responsible for algae growth in KTR and the canals. Algae along with sediments found in the irrigation water supply can play havoc on drip irrigation systems and will require upgrades in existing filtration processes. High pH in the water will likely cause calcite precipitation within drip emitters which will require acidification to drop the pH to acceptable levels.

Trace elements are only unlikely to limit the long-term reuse. Particular attention should be given to Mn, Mo, Li and V due to their concentrations in the irrigation water being close to the guidelines, which are based on long-term use for irrigation or crop sensitivity.

The long-term sustainability of irrigated agriculture in the Jordan Valley using KTR water is viable. However, this requires good management, both by the farmers and producers, and the Jordan Valley Authority. The required on-farm water management needs, among, other things, an effective extension service.

I. INTRODUCTION

I.1. BACKGROUND

Water supplies are scarce in Jordan and are likely to be even more limiting in the future. Population levels, particularly in the Amman-Zarqa area, are projected to increase in the years to come. This will stress its already limited supply of water for agriculture, urban and industrial uses. Effluent discharges into Wadi Zarqa are projected to increase from 66 M-m^3 in the year 2000 to 185 M-m^3 per annum in 2025 (ARD, 2000). In the middle and southern (Karameh) directorates of the Jordan valley, the proportion of treated effluent in the water supply from KTR will increase and irrigated agriculture in these areas will have to depend on water of this quality.

The Jordan valley has an excellent climate for growing a wide range of crops but irrigated agriculture is limited by its water and to some extent soil resources. Much of the already scarce water supplies are poor in quality. Soil quality varies throughout the valley where those most suitable for irrigated agriculture are generally found in the Northeast while those most problematic are found in the Southwest. Irrigation systems are predominately drip, yet surface irrigation and a small amount of sprinkler irrigation exists. Evidence indicates that the efficiency of these systems and overall irrigation management can be improved substantially, both before and after the farm gate (Hagan, 1998, personal communication).

Because the water supply in Jordan is limited, it is essential that every opportunity be taken to optimize existing water resources including improvements in use efficiency and water reuse. As indicated in the Water Policy of Jordan, Policy Paper No. 2 (1998), wastewater should be viewed as a water resource. These efforts however are not without a price. Improvements in efficiency require upgrades in the existing delivery system, extension education and better on-farm water management. Crops more sensitive to salinity will be impacted more than those more tolerant which will likely influence existing cropping patterns in the valley. Effluent from wastewater treatment plants contain a number of constituents that when used for irrigation can affect either crop yield or crop quality; limit the type of crops that can be grown effectively; affect irrigation system maintenance and management; or affect the marketability of the crop.

In light of the concern over the continuing degradation of water quality and use of recycled water for irrigated agriculture, irrigation management will have to be extremely careful to assure that agriculture is sustained over the long-term. This report provides input regarding the potential long-term impact irrigation with undiluted KTR water will have on crop production, soil conditions and irrigation management.

I.2. SPECIFIC OBJECTIVES

- Characterize existing cropping patterns, irrigation water quality, soil resources, and irrigation management practices in the Jordan valley.

- Quantify the potential impact of irrigation with undiluted KTR water on yields of major crops in the Jordan valley.

- Identify water quality parameters that are most appropriate for assessing the suitability of irrigation using KTR water and assess the potential impacts and implications of each of those parameters.

II. CURRENT ASSESSMENT OF CONDITIONS IN THE JORDAN VALLEY

II.1. Irrigation Water Quality

The quality surface water supplies vary throughout the valley (Forward, 1999). The highest quality water is from Abu Sido, Kreimah, Wadi Kufrinja, Kufrein dam and Wadi Shueib dam. Water of this quality, with the exception of a few constituents, provides little restriction on crop production. Water supplies that receive KTR water or dilutions of this water are considered intermediate quality and water from the Karameh dam is considered poor quality. KTR water and to a greater extent Karameh dam water, pose a number of restrictions and in particular, the number of crops that can be grown to their full yield potential.

II.1.1. Water North of the KTR-KAC confluence.

Water in the King Abdullah Canal (KAC) north of the confluence of the KAC and KTR is of good quality (Table 1). Canal water in this region is for the most part a mix of water from the Yarmouk River, Mukheibeh well, and Wadi Al Arab Reservoir. The salt and nutrient content of this water is generally low because this water does not receive treated effluent.

II.1.2. KTR Water

KTR water is a mix of recycled water from Amman and runoff water from Wadi Zarqa. This water is often used undiluted in the Zarqa triangle or used undiluted and/or mixed, depending upon time of year and annual rainfall, with KAC water in the middle and Karameh directorates. The salt and nutrient content of this water is substantially higher than KAC water (Table 1) and will have a greater impact on crop production and overall management than KAC water. The average salt content of the effluent has been relatively stable over the past decade (ARD, 2000), but in 1999 there has been a slight increase in salinity presumably due to the drought Jordan has been experiencing.

II.2. Soil Conditions

Soils vary considerably within the Jordan valley (Awni Taimeh, 1998, NCARTT, personal communication). Particularly characteristic of the soils is the presence of Lisan Marl (locally called “Katar”). This is a cemented hard layer comprised of salts, gypsum and carbonates. The depth to this restricting layer varies throughout the valley. In the Northeastern part of the valley, soils are well drained and the depth to the Marl layer maybe 2 to 3 meters. However as one moves towards the Southwest, the depth to the Marl layer becomes progressively more shallow. Between Deir Alla and just North of Karameh clusters of gypsum in the soil profile can be found. In the Southern portion of the valley (at Karameh dam and south), the depth of the Marl can vary from less than one meter to exposure at the soil surface. As a consequence, soils are more difficult to manage and they are characteristically more saline is this area. Very shallow soils and those formed primarily from Marl parent material should be discouraged from cultivation because of the natively high contents of salt and poor internal drainage (Awni Taimeh, 1998, personal communication).

The type and distribution of soils are important because they impact the type and level of management that needs to be exercised to optimize production. Although crops can be grown on a rather wide range of soil types, it is necessary that they are able to drain. Those that have a restricting or impermeable layer close to the soil surface are subjected to the formation of a perched water table, preventing the downward movement of salt out of the crop root zone. Without drainage, a salt-balance cannot be achieved and threatens the sustainability of irrigated agriculture in that area.

II.3. Importance of Leaching and Drainage to Control Salinity

The key to successful irrigation using water that is more saline for irrigation is maintaining an adequate salt balance in the crop rootzone such that the accumulation of salts do not occur. Because the overall projected flow of water from KTR will increase in the future, achieving this goal should be easier in the years to come provided irrigated agriculture does not expand beyond its means.

All plants have an upper tolerance limit to the salt concentration in the root zone without damage. Therefore, some downward displacement of salts below the rootzone, commonly referred to as leaching, is a necessity regardless of plant type or conditions to maintain plant productivity. The amount of leaching is dependent on the salt tolerance of the plant and the salinity of the irrigation water: the greater the salt-tolerance, the lower the required leaching.

Leaching can only occur when there is adequate drainage. Some soils are naturally deep and well drained and leaching can be achieved easily, at least on a seasonal basis, provided that the farmer is supplied with sufficient quantities of water. Other soils, on the other hand, have a restricting sub-surface layer that does not allow water to move vertically downward in the soil profile such as the Marl layers that exist close to the soil surface in many areas within the southern parts of the Jordan valley.

When drainage is not adequate, a buildup of salts can occur. It is often misunderstood that plant roots, for the most part, extract "pure water" from the soil water leaving the salts behind. The amount of nutrients that the plant-roots selectively remove from the soil solution is negligible compared to the bulk of the salts that remain. As the crop consumes this "pure" water from the soil, a smaller and smaller volume of water remains, thereby concentrating the salts. These salts must be leached from the soil. If drainage is not adequate, leaching cannot take place, allowing salts to build up in the rootzone and affect crop production.

Artificial drains have been installed in a number of areas within the valley to increase the ability to leach the soils to avoid the build-up of salts. It is estimated that about 20-25,000 dunums are drained in the valley (Mohamed Hambali and Mohamed Foad Hassan, 2000, MWI, personal communication). In the north, drains are installed in DA 3-16. In the middle directorate, DA21, 22, 23, and 29. In the Karameh directorate, DA25, 26 and 27. These individuals indicate that the drains function and are currently maintained by the Northern, Middle and Karameh Directorates independently. Maintaining well-drained conditions in the areas that will use the more saline KTR is a key factor in the success of the area.

In accordance with Governmental policy, additional drainage networks should be installed in irrigated areas where natural drainage is insufficient (Irrigation water policy, paper No.2, 1998). Although effective, installation of drains are expensive. Furthermore there are areas where installation of drains may even be inadequate such as shallow soils where the Marl layer approach the soil surface. This is particularly common in soils south of Karameh. It is recommended that problematic soils (i.e. those that are shallow or where installation will be ineffective) be identified and restricted from cultivation.

II.4. Cropping Patterns

Despite the limitations in the country's water and soil resources, the Jordan valley hosts a number of crops. A list of the major crops currently grown in the Jordan valley is found in Appendix 1 in relation to stage office (SO) and directorate. A major crop is considered any crop where the cultivated area is over 1% of the total cultivated area in the stage office. This appendix was developed based on the cropping patterns from 1998. Citrus, vegetables, bananas, grapes and certain stone and late season fruits dominate the Jordan valley.

In the northern directorate (SO 1, 2 and 7), citrus is by far the most predominate crop in the region comprising over 50% of the 79 thousand dunums of cultivated land in the area. Tomato and banana are the next most prevalent crops covering about 8 and 6% of the cultivated area respectively. All other major crops make up about a third of the remaining cultivated land with no one crop making up more than 4%. Most of the bananas are grown in SO1 while most the tomatoes are grown in SO 2 and 7. Potato is primarily grown in SO 2.

In the Middle directorate (SO 3, 4, 5, and 8) potato, citrus and tomato are the dominate crops making up about 38% of the total cultivated land (99 thousand dunums) is this directorate. These are the same top three crops as found in the northern directorate, only the order has changed. Vegetables such as squash, onion, cucumber and pepper each make up between 5-9% of the irrigated land. Citrus and tomato are concentrated mainly in SO 3 and 8. Potato is also dominate in these stage offices as well as stage office 5. Onions on the other hand are more common in SO 4 and 8.

In the Karameh directorate (SO 6, 9 and 10), malok, banana, melons, and eggplant dominate covering 22, 16, 13 and 10% of the 17 thousand dunums of irrigated area. Citrus, tomato, stone fruit, grapes, squash, okra and lettuce each account for between 2 to 7% of the cultivated land in this directorate. Six additional major crops consisting of miscellaneous vegetables, fruit trees, and grain crops cover most of the remaining cultivated area in this directorate.

Based on 1998 cropping patterns, 90% of the irrigated agriculture is in the Northern and Middle directorates. The middle and Karameh directorate, where most of the KTR water will be used consists of about 60% of the cultivated area[1]. Most of the crops currently grown in the Jordan valley fall within the sensitive to moderately salt-sensitive category (see Maas and Grattan, 1999).

II.5. Irrigation Management

There are a number of cases around the world where saline water has been used successfully for irrigation (Grattan and Rhoades, 1990; Rhoades et al., 1992). Use of more saline water for irrigation, however, requires several changes from standard irrigation practices such as selection of appropriate crops, special care in managing and monitoring soils and water, changes in cropping patterns and in some cases, the adoption of advanced irrigation technology.

Poor quality water affects a number of practices at the farm level. As the quality of irrigation water is degraded, the margin of safety is reduced in regards to irrigation management. Irrigation with a more saline water for example requires increased flexibility in water delivery schedules and care that soil salinization does not occur. This is particularly true for drip irrigation systems where roots are restricted to smaller volumes within the soil profile, compared to those surface-irrigated crops.

As it currently exists in much of the Jordan valley, irrigation water is available to growers only two to three times per week (Hagan and Taha, 1997). This type of delivery schedule is more conducive for surface irrigation than drip irrigation methods. The combination of poor quality water and extended intervals between irrigations will impose additional stress and intensify salinity's effect on the crop. As such, farmers in the Jordan valley with drip irrigation try to improve their flexibility by building reservoirs or holding ponds on the farm. In the process, the grower loses the original pressure in the system and now needs a pump to supply water from the storage pond to the crops. The JVA and growers within each of the stage offices need to change existing practices to allow for irrigation water on immediate demand in order to optimize crop production.

The Water Quality Improvement and Conservation Project (1997), recommend that JVA share irrigation network system management responsibilities with their user (i.e. the grower). Although it is recognized that such a "shared responsibility" would be a major change in the existing operation, it may lead to improvements in overall system efficiency and flexibility.

In the Zarqa triangle, where KTR water is currently used undiluted, the condition and operation of the current system has potential for improvements. For example, although water meters are installed, most are not operational (Mohamed Yussef Hamdan, 2000, Zarqa grower, personal communication) and therefore the charges for irrigation water are based on the design flow (liters per second) and not actual

1 Cultivated area for annual crops was estimated based on cultivated area for a given region within the year. Therefore in a few cases, more than one crop was grown on a particular field within the year.

flow (meter) (WQIC, 1997). Many pipes are old and leak and in some cases, growers take unmetered (and thus unbilled) water while others do not get their water allotment because the “ditchrider” decides to go home early (WQIC, 1997).

II.6. Irrigation Method.

The method of irrigation can affect the crop’s response to salinity because it will influence the salt distribution in the soil, determines whether the leaves will be subjected to wetting and determines the ease at which high soil-water potentials can be achieved (Maas and Grattan, 1999). Since irrigation methods that maintain a higher soil-water potential reduce the time-averaged salt concentration in the soil-water (such as drip), they allow for optimal plant performance if the systems are operated and maintained properly.

In the Zarqa triangle, about half the irrigation systems are drip while the other half are furrow (WQIC, 1997). Santanawi et al. (1994) estimated that the surface irrigation system in this area was, on the average, 70% efficient while the drip systems were only 56 % efficient. Although drip systems, if operated optimally, have a potential to achieve a high application uniformity and be more efficient in heterogeneous soil conditions, clogging of emitters can cause dramatic reductions in uniformity and overall system performance.

Sprinkler irrigation with even marginal quality water can cause substantial injury to a number of crops and therefore potentially reduce yields beyond that based on soil salinity alone (Maas and Grattan, 1999). In these cases salts can readily enter the leaf with the crop is wetted by sprinkler irrigation and becomes more problematic as the frequency of irrigation increases.

Currently, sprinkler irrigation in not wide spread in the Jordan valley (Avadies Serpekian and Ross Hagan, personal communication). Consequently, additional crop damage due to injury from foliar absorption of salts may only be localized in rare situations. However should sprinkler irrigation be expanded in the future, it is important to note that the yield potential estimates in this report will likely be underestimated.

III. KTR WATER-QUALITY IN RELATION TO DIRECT AND INDIRECT IMPACTS ON IRRIGATED AGRICULTURE

Effluent that is discharged into KTR degrades water quality in the reservoir. Concentrations of a number of inorganic and organic constituents are increased due to additions of this effluent including salts, nutrients and potential pathogens. These constituents can adversely affect crop production, maintenance of the delivery systems, management on-farm, pose a threat to human health and potentially restrict the types of crops where this water is intended to be used.

The water quality at the outlet of the KTR is drastically different from that in the KAC (Table 1). Particularly significant are the salt content (ECw, Na, Cl, etc), nutrients, and certain trace element concentrations.

Table 1. Average water quality data from 1994-99 and 1999 alone from sampling locations C2 (representing good quality KAC water) and sampling location 600 (representing KTR water at the outlet).

		KTR - STA. 600 (OUTLET)		KAC - C0	
Parameters	**Units**	**Average 99**	**Average 94-99**	**Average 99**	**Average 97-99**
Physical					
EC	µs/cm	2435.1	1911.94	1051.8	982.9
pH	SU	7.9	7.76	8.4	8.2
SAR	-	4.74	3.75	2.1	2.1
TSS	mg/l	13.6	20.2	41.6	55.8
Cations					
Na	mg/l	253.18	191.48	87.2	85.8
Ca	mg/l	117.18	117.46	76.9	71.2
Mg	mg/l	56.82	45.93	32.5	30.4
K	mg/l	36.6	29	8.7	8.5
Anions					
Cl	mg/l	409.8	322	132.3	123.8
SO4	mg/l	155.7	139	90.8	86.4
HCO3	mg/l	573	508	295.4	281.8
Nutrients					
TP	mg/l	7.25	5.62	0.4	0.4
PO4-P	mg/l	6.23	4.93	0.2	0.3
TN	mg/l	29.82	26.05	3.9	4.3
NO3-N	mg/l	2.9	1.96	2.8	3.1
NH4-N	mg/l	21.7	19.4	1	1
Trace Elements					
B	mg/l	0.6	0.6	0.1	0.1
Cd	mg/l	0.003	0.0033	-	-
Co *	mg/l	0.05	0.026	-	-
Cr	mg/l	0.025	0.0138	-	-
Cu	mg/l	0.025	0.0123	-	-
F *	mg/l	-	0.516	-	-
Hg **	mg/l	0.001	0.0008	-	-
Li *	mg/l	0.033	0.026	-	-
Mo *	mg/l	0.01	0.079	-	-
Mn	mg/l	0.19	0.18	-	-
Pb	mg/l	0.01	0.0132	-	-
Se **	mg/l	0.005	0.006	-	-
V **	mg/l	0.1	0.0767	-	-
Zn	mg/l	0.0118	0.009	-	-
Microbial					
TFCC	MPN/100ml	15021.3	5743	5463.6	3584.5
Nematodes	Egg/l	0	0	0	0
* Data for these elements available since 1996					
** Data for these elements available since 1997					

Water quality can impact irrigated agriculture in a number of ways. Below is a list of specific water quality parameters and their potential impact on various aspects of crop production, management, maintenance and human safety (Table 2). Each aspect will be discussed individually in relation to the various water quality parameters, both regarding their importance and potential impact on crop lands irrigated with KTR water.

Table 2. Important water quality parameters and their potential affect on irrigated agriculture, either directly or indirectly.

Potential Impact on Irrigated Agriculture	Water Quality Parameter(s)
Salinity Hazard (i.e. Yield Potential)	ECw
Crop Toxicity (i.e. visual crop injury)	Boron (B), Chloride (Cl), Sodium (Na)
Accumulation of Trace Elements	All heavy metals and trace elements
Water Infiltration Hazard	ECw, SAR
Crop Nutrient Requirement	N and P
Clogging of Drip Emitters	Suspended Solids, N, P (algae), pH, HCO_3
Public Health, Consumer confidence	Total fecal coliforms, Nematodes

The electrical conductivity of the irrigation water is an indicator of the salinity hazard of the water and increases as the salt content of the water increases. This single parameter is most important for assessing the potential impact of salts in the water supply on crop production.

The other water quality parameters affect crop production but there is no means of quantifying their effect. Sodium, chloride and boron, if present in sufficient quantities can injure permanent crops such as citrus, grapes and banana. Nitrogen and phosphorus, although crop nutrients, can cause algae problems in KTR and conveyance systems which then lead to clogging problems in drip irrigated crops. High nitrogen late in the season may also cause crop quality problems. Sediments (i.e. suspended solids) and waters high in pH can also cause major clogging problems. High SAR may lead to soils with reduced water infiltration rates. Therefore these additional water quality parameters are important to consider since they will impact management and maintenance of irrigation systems both before and after the farm gate.

III.1. Salinity Harzard (i.e. Yield Potential)

Salinity affects crop production in two ways; by osmotic effects and specific-ion effects (Läuchli and Epstein, 1990). The most common whole-plant response to salt-stress is a general stunting of growth. This is generally referred to as an osmotic effect and is directly related to the salt content in the soil water. This in turn is related to the salinity in the irrigation water and the extent of leaching that takes place. As salt concentration in the crop rootzone increases above a threshold level, both the growth rate and ultimate size of the crop progressively decrease. However the threshold and the rate of growth reduction vary widely among different crop species. Some crops such as common bean, strawberry and most fruit trees are highly sensitive to salinity and begin to show reductions in growth at very low levels. Tolerant crops such as barley, asparagus and date palm, on the other hand, can tolerate much higher salinity levels.

The water quality parameter used to assess salinity's impact on crop production (i.e. yield potential) is the electrical conductivity of the irrigation water (ECw). This parameter can then be used to estimate the soil salinity (ECe) with the assumption of long-term irrigation and a leaching fraction. The leaching fraction (LF) is the fraction of infiltrated water that percolates past the crop root zone.

III.2. Yield Potential

Yield potential was determined based on the Maas-Hoffman salinity-coefficients (Maas and Grattan, 1999) and the relationship between ECw (electrical conductivity in the irrigation water) and ECe (average rootzone salinity expressed as the EC of the saturated soil extract) assuming steady-state conditions and a leaching fraction of 15-20% (Ayers and Westcot, 1985). This value denotes the maximal yield potential a crop can achieve given the water quality and achievable leaching-fraction. Other factors such as extreme climactic conditions, poor soil conditions, inability to leach, inadequate drainage and long intervals between irrigations could aggravate the salinity problem such that the yield potential will be less than indicated here. These additional factors are important to consider for conditions here in the Jordan valley. Nevertheless, this yield potential estimate provides a good baseline value that is useful for planing and educating.

Maas and Hoffman (1977), as described by Ayers and Westcot (1985) proposed that salt-tolerance can best be described by plotting its relative yield as a continuous function of average rootzone soil salinity (ECe). They proposed that this response curve could be represented by two line segments; one, a tolerance plateau with a zero slope and the second, a concentration-dependent line whose slope indicates the yield reduction per unit increase in soil salinity (Figure 1).

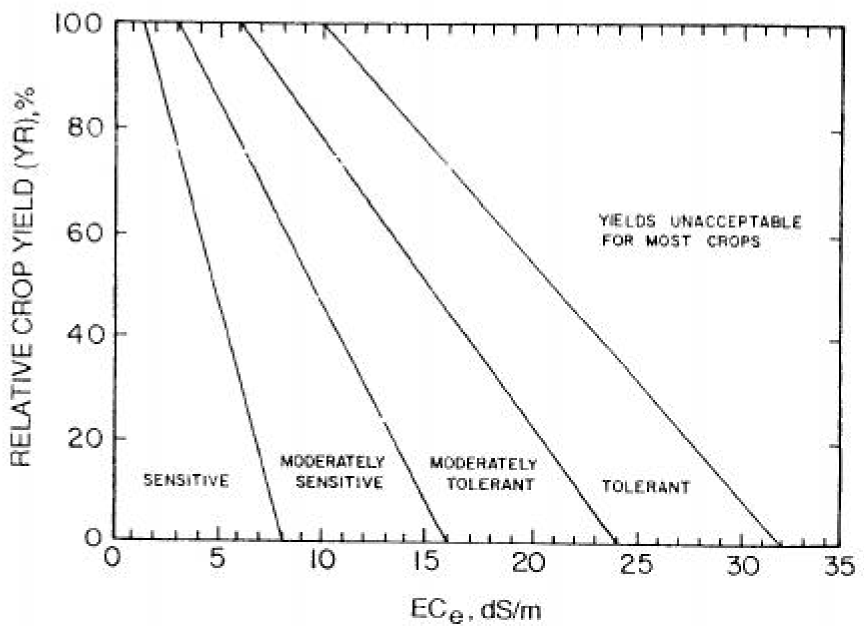

Figure 1. Divisions for salt-tolerance classifications (Source: Ayers and Westcot, 1985)

For soil salinities exceeding the threshold of any given crop, relative yield (Yr) or "yield potential" can be estimated using the following expression:

$$Yr\ (\%) = 100 - b(ECe - a)$$

where a = the salinity threshold soil salinity value expressed in dS/m; b = the slope expressed in % per dS/m; and ECe = average rootzone salinity in the saturated soil extract. Specific values for "a" and "b", called “salinity coefficients” are found in a publication by Maas and Hoffman (1977) or more recently by Maas and Grattan (1999). The greater the threshold value and lower the slope, the greater the salt tolerance.

In order to assess the impact of irrigation water with a known ECw on crop yield, the relation between irrigation water salinity and soil salinity needs to be known. FAO 29 lists the relationship between ECw and ECe for various leaching fractions and assuming steady-state conditions (Ayers and Westcot, 1985). For a leaching fraction of 15-20%, a reasonable estimate under good irrigation water management conditions, ECe = 1.5 (ECw).

The leaching fraction is defined as the fraction (or percentage) of infiltrated water that drains below the rootzone. For example if 5 ha-cm of water was applied to a one hectare field and 1 ha-cm of water drained below the rootzone, the leaching fraction would be 0.20 or 20%.

Steady-state conditions are never achieved under field conditions but these relationships serve as both a target and a guide. Leaching must eventually be satisfied to prevent salt accumulation.

The ECw-ECe relationship does not always hold true, particularly in gypsiferous soils. Some soils in the Jordan valley many of which are found in the south where the Marl layer is close to the soil surface, have gypsiferous charcteristics. In the reference by Maas and Grattan (1999), it is suggested that crops grown in gypsiferous soils will tolerate an ECe of about 2 dS/m higher than would otherwise in non-gypsiferous soils. Similar to that approach adopted by Forward (1999), an adjustment is not used here because such an adjustment would first require an added adjustment to the predicted ECe to a given area high in gypsum (if known) to account for the background salinity but then subtracted out later because crops tolerate 2 dS/m higher ECe in the presence of gypsum.2

To illustrate how the yield potentials were calculated, the following example is provided. The average ECw of KTR water from 1994-99 is 1.9 dS/m at the KTR outlet (sampling site 600). If this water were the only source to irrigate crops and an average leaching fraction of 15-20% could be achieved, then the average rootzone salinity (i.e. soil salinity) would be 2.85 dS/m. If beans were the crop, then the yield potential would be;

$$Yr = 100 – b(ECe – a)$$

The salinity coefficients for bean are a=1 and b=19.

Therefore Yr = 100 – 19(2.85 – 1) = 65%

Beans are sensitive to salinity and as a consequence the highest potential yield that a grower could expect is 65%. Extended intervals between irrigations that induce an additional stress on the crop would drop the yield potential even more.

2
The baseline soil salinity (ECe of about 2 dS/m) will be present in gypsiferous soils if non-saline water is used. Therefore if saline water is used the actual ECe will be higher than the ECw-ECe relation indicates. Crops, on the other hand, will tolerate a higher ECe. This assessment focused on the differences in yield that might result if undiluted KTR water is used in place of higher quality KAC water. Thus the effect of a soil characteristic to a large degree cancels itself out when comparing the same location but with different water qualities.

If an adjustment of this nature were to be used, then a difficult and uncertain task would present itself of dealing with a huge matrix of interactions between the chemical composition of the water and interactions with the soil. The computer model WATSUIT is particularly suitable to make such predications but this would have required a database significantly better than was available to the project or available within Jordan. With these limitations in mind, it was decided to use the less data intensive Maas-Hoffman approach as detailed in FAO 29 (Ayers and Westcot, 1985) to obtain yield predictions. This allowed the project to focus on the bigger issue of the potential impact that would occur if undiluted water were used for irrigation in replacement of KAC water.

The yield potentials for major crops grown in the Jordan valley are presented in Table 3. These yield potentials are determined based on crops being irrigated with the particular water source (KAC or KTR) over the long term.

Table 3. Yield potentials of the major crops grown in the Jordan valley based on an average leaching fraction of 15-20% over the long term.

CROP	EC (KAC)	ECE	a	b	Yield (KAC)	EC (KTR 94-99)	ECE	Yield (KTR)	EC (KTR 99)	ECE	Yield KTR-99
Apple	1	1.5	1.5	20	100	1.9	2.85	73	2.4	3.6	58
Apricot	1	1.5	1.6	24	100	1.9	2.85	70	2.4	3.6	52
Asparagus	1	1.5	4.1	2	100	1.9	2.85	100	2.4	3.6	100
Banana	1	1.5	1.5	20	100	1.9	2.85	73	2.4	3.6	58
Barley	1	1.5	8	5	100	1.9	2.85	100	2.4	3.6	100
Bean	1	1.5	1	19	91	1.9	2.85	65	2.4	3.6	51
Cabbage	1	1.5	1.8	9.7	100	1.9	2.85	90	2.4	3.6	83
Carrot	1	1.5	1	14	93	1.9	2.85	74	2.4	3.6	64
Cauliflower	1	1.5	2.8	9.2	100	1.9	2.85	100	2.4	3.6	93
Citrus, Grapefruit	1	1.5	1.2	13.5	96	1.9	2.85	78	2.4	3.6	68
Citrus, Lemon	1	1.5	1.5	12.8	100	1.9	2.85	83	2.4	3.6	73
Citrus, Orange	1	1.5	1.3	13.1	97	1.9	2.85	80	2.4	3.6	70
Corn, Maize	1	1.5	1.7	12	100	1.9	2.85	86	2.4	3.6	77
Cucumber	1	1.5	2.5	13	100	1.9	2.85	95	2.4	3.6	86
Dates	1	1.5	4	3.6	100	1.9	2.85	100	2.4	3.6	100
Eggplant	1	1.5	1.1	6.9	97	1.9	2.85	88	2.4	3.6	83
Fig	1	1.5			100	1.9	2.85	100	2.4	3.6	100
Forage, Alfalfa	1	1.5	2	7.3	100	1.9	2.85	94	2.4	3.6	88
Forage, Bermuda grass	1	1.5	6.9	6.4	100	1.9	2.85	100	2.4	3.6	100
Forage, Berseem	1	1.5	1.5	5.7	100	1.9	2.85	92	2.4	3.6	88
Garlic	1	1.5	3.9	14.3	100	1.9	2.85	100	2.4	3.6	100
Grapes	1	1.5	1.5	9.6	100	1.9	2.85	87	2.4	3.6	80
Guava	1	1.5	4.7	9.8	100	1.9	2.85	100	2.4	3.6	100
Legumes, Pea	1	1.5	3.4	10.6	100	1.9	2.85	100	2.4	3.6	98
Lettuce	1	1.5	1.3	13	97	1.9	2.85	80	2.4	3.6	70
Melon	1	1.5	1	8.4	96	1.9	2.85	84	2.4	3.6	78
Olive	1	1.5			100	1.9	2.85	100	2.4	3.6	100
Onion	1	1.5	1.2	16	95	1.9	2.85	74	2.4	3.6	62
Peaches	1	1.5	1.7	21	100	1.9	2.85	76	2.4	3.6	60
Pepper	1	1.5	1.5	14	100	1.9	2.85	81	2.4	3.6	71
Potato	1	1.5	1.7	12	100	1.9	2.85	86	2.4	3.6	77
Radish	1	1.5	1.2	13	96	1.9	2.85	79	2.4	3.6	69
Spinach	1	1.5	2	7.6	100	1.9	2.85	94	2.4	3.6	88
Squash, Zucchini	1	1.5	4.9	10.5	100	1.9	2.85	100	2.4	3.6	100
Strawberries	1	1.5	1	33	84	1.9	2.85	39	2.4	3.6	14
Sweet potato	1	1.5	1.5	11	100	1.9	2.85	85	2.4	3.6	77
Tomato	1	1.5	2.5	9.9	100	1.9	2.85	97	2.4	3.6	89
Turnip	1	1.5	0.9	9	95	1.9	2.85	82	2.4	3.6	76
Wheat	1	1.5	6	7.1	100	1.9	2.85	100	2.4	3.6	100

Because bananas are sensitive to salinity (Maas and Grattan, 1999) and no salinity coefficients are provided, values similar to sensitive trees was assumed.
Salinity coefficients for broccoli was assumed for cauliflower.

With the exception of strawberries, crops can be irrigated with KAC water and achieve at least 90% of their yield potential. If beans and carrots are added to the exception, crops can be grown to over 95% of their yield potential. Therefore the salinity hazard of this water is very low and all crops can be grown and sustain reasonable yields provided soils are well drained and salinity buildup is prevented.

The yield potential of salt sensitive and moderately salt-tolerant crops irrigated with KTR water, on the other hand, will be impacted more. For example if the ECw of the KTR water is 1.9 dS/m, then the yield potential of strawberries and beans will be 39 and 65%. Nevertheless, 72% of the crops listed in table 3 including citrus, can be grown at 80% or more of their yield potential.

If the quality of KTR water were to stabilize at the 1999 level, then the salinity of the water would be 2.4 dS/m. This slight increase produces a significant increase in potential damage. In this case only about half of the major crops listed in table 3 would be grown at 80% or more of their yield potential. Therefore a slight increase of only 0.5 dS/m in this marginal salinity range could have devastating effects on the crops currently grown.

Particularly affected by KTR water, in addition to strawberries and beans are banana, stone fruits, apples, onions and carrots. Citrus is also somewhat sensitive salinity but will also be affected by Cl and possibly Na (see below).

Crops that appear to be rather suitable for irrigation with KTR water (i.e. can be grown to at least 90% of their yield potential) are asparagus, cauliflower, dates, fig, garlic, guava, peas, olive, squash and many forage and grain crops. This should not be included as an exclusive list. There are a number of other crops (currently not listed as “dominate crops”) that could be grown as well.

The cropping patterns by stage office are illustrated in appendix 2. Each of the crops are color-coded based on the potential yield should they be irrigated on a sustained bases with KTR water with an ECw of either 1.9 or 2.4 dS/m. All stage offices contains crops that will be adversely affected by irrigation with KTR water. It is important to note that citrus is the dominate crop in each of the three stage offices in the north. Currently these stage offices are not irrigated with KTR water but should they receive this water, citrus could suffer not only from salts in general but from chloride toxicity (see below).

It is also important to mention that future cropping-patterns will not necessarily follow relative rankings in salt tolerance but rather will reflect economic return to the grower and perhaps a number of other factors. For example it may well be worth a grower to grow melon at 70% yield potential than a salt-tolerant forage at 100%. Therefore no predictions are made regarding how actual cropping patterns will shift. Because onions and beans are two of the most sensitive crops to salinity, it is possible that percentage of this crop currently grown in SO 4 and 8, for example, will decrease in the future. If injury and yield losses in citrus become too great, it is possible the orchards may be removed and replaced with more tolerant crops. However this may take a number of years before severe injury and loss occur.

In summary, use of KTR will reduce the yield potential of most crops grown in the Jordan valley. However if proper irrigation management is exercised and water delivery schedules can be changed allowing growers use on a daily or every other day basis, then 72% of the current crops can be grown to 80% or more of their yield potential. If however salinity increases to 2.4 dS/m on a sustained basis, only half the crops can be grown to at least 80% of their yield potential. On a positive note, more reclaimed water will be available for irrigation provided the irrigated area does not increase, allowing more water for leaching during winter months. Consequently, the success lies on the ability of the grower to adopt best management practices for use of saline water.

III.3. Crop Toxicity

Salinity can also affect crop production directly from toxicity due to specific ions. Certain crops, particularly trees and vines, are sensitive to chloride (Cl), sodium (Na) and boron (B) in the irrigation water and can develop injury to leaves or stems if concentrations exceed certain levels. Specific-ion injury, if severe enough, will reduce yields beyond that predicted by the salinity of the irrigation water in table 3. Threshold levels in the irrigation water that produce such injury are reported in FAO 29 (Ayers and Westcot, 1985).

Potential hazard to specific-ion toxicity increases if the crop foliage is wetted by sprinkler irrigation. Since sprinkler irrigation is not dominant in the valley (i.e. less than 5%, Avadies Serpekian, 1998, personal communication), potential hazard due to these elements will be based on irrigation systems that do not wet the foliage (i.e. surface and drip). However caution is advised should KTR water be considered for irrigation in the future or used frequently for sprays to treat plants for pests.

III.3.1. Chloride (Cl) Toxicity

Many woody species are susceptible to Cl toxicity which varies among varieties and rootstocks within species. The degree of susceptibility is often reflected in the plant's ability to restrict or retard Cl translocation to the tops (Maas and Grattan, 1998). For example salt-tolerance in grapes, grapefruit and orange is closely related to the Cl accumulation properties of the rootstock. By selecting rootstocks that exclude Cl from the scions, some degree of Cl toxicity problems can be avoided.

The maximum Cl concentration in the irrigation water that can be used by a particular crop to avoid leaf injury can be found in FAO 29 (Ayers and Westcot, 1985). This list is by no means complete since data for many cultivars and rootstocks are not available. Original data listed by Maas and Hoffman (1977) are in relation to maximal Cl concentrations in the soil water, but data were converted to maximal tolerance in the irrigation water by Ayers and Westcot (1985) using some reasonable assumptions (Table 4). It was assumed that the Cl concentration in the soil water is about twice that in the saturated soil paste and that a 15-20% leaching fraction is used. The guidelines also assume that the crops are not irrigated by sprinklers that wet the leaves allowing salts to enter the leaf by direct foliar absorption.

Table 4. Maximum Cl concentrations in the irrigation water that various tree and vine rootstocks can tolerate without developing leaf injury. Assumes 15-20% leaching fraction using irrigation management practices that do not wet the leaf (Source: Ayers and Westcot, 1985).

Crop	Rootstock or Cultivar	Maximum Cl concentration (mg/L)
Citrus	Sunki mandarin	600
	Grapefruit	600
	Cleopatra mandrin	600
	Rangpur lime	600
	Sampson tangelo	350
	Rough lemon	350
	Sour orange	350
	Ponkan mandrin	350
	Citrumelo 4475	250
	Trifoliate orange	250
	Cuban shaddock	250
	Calamondin	250
	Sweet orange	250
	Savage citrange	250
	Rusk citrange	250
	Troyer citrange	250
Stone fruit	Marianna	600
	Lovell	250
	Shalil	250
	Yunan	180
Grape	Thompson seedless	460
	Perlette	460
	Cardinal	250
	Black rose	250
Strawberry	Lassen	180
	Shasta	100

The chloride concentration in KAC water is about 124 mg/L (Table 1). Water of this quality can be used to irrigate all crops (Ayers and Westcot, 1985) provided good irrigation management is exercised and soils have good drainage.

The Cl concentration in water from KTR (322-410 mg/L) however may pose a threat to certain trees and vines depending upon the rootstock or variety. These guidelines provided in FAO indicate that the maximum Cl concentration of the irrigation water to avoid crop injury is about 250 mg/L for sensitive rootstocks on citrus and grapes. The Cl concentration in KTR water exceeds this value. Note that there is a number of citrus rootstock that can tolerate up to 350 or even 600 mg/L without developing injury.

It is important to note that research in incomplete regarding the evaluation of modern or commonly used rootstocks for Cl tolerance. Therefore it is possible that rootstocks not mentioned in FAO29 may be more or less tolerant than those indicated in table 4. In addition, no Cl toxicity ratings are provided for banana. Banana, being a crop of tropical nature and accustomed to highly leached soils, could very well be susceptible to Cl injury but this is only speculation.

Chloride toxicity for most vegetable and agronomic crops is not considered a major problem except for beans using KTR water and in cases where the foliage is wetted under sprinkler irrigation. Usually by the time Cl injury is evident on annual crops, these plants are already experiencing severe salinity stress.

In summary, Cl toxicity is not likely to be problematic if KAC water is used for irrigation unless soils are poorly drained and natively high in salts. Cl toxicity can be moderately problematic for citrus, grapes and other fruit trees in areas that use KTR water. Because of the high capital investment associated with tree and vine crops and their overall sensitivity to both salinity and chloride, it is recommended that these crops are not irrigated with KTR water.

III.3.2. Boron (B) Toxicity

Boron is an essential element for the crop but has a small concentration window between deficiency and toxicity. Certain crops, particularly trees and vines, are sensitive to B in the irrigation water and can develop injury to leaves or stems if concentrations exceed certain limits. Boron injury, if severe enough, will likely reduce yields beyond that predicted by EC alone but few data are available to predict such a yield loss.

Historically, the boron concentration in KTR water has not always been low. Harza (1996) has shown that boron concentrations have fallen since regulations were put in place in 1991 that prohibits the use of boron-based detergents. Therefore because of this governmental action, the boron concentrations are likely to remain low. In almost all surface water sources, boron concentrations are low throughout the system and increases in concentration for the most part reflect evapo-concentration.

Threshold levels in the irrigation water that produce such injury are reported in FAO 29 (Ayers and Westcot, 1985). The existing B tolerance data can only be used to indicate the maximum concentration above which such a plant injury is likely to occur. Guidelines in FAO 29 indicate the irrigation water with concentrations less than 0.7 mg/L can be used to irrigate all major crops in the Jordan Valley without restriction on use.

Based on data from both the KAC (0.1 mg/L) and the outlet to KAC (0.5 mg/L), the boron hazard is low. Caution is advised, however, since these guidelines assume that leaching takes place and they do not account for situations where soils are natively high in boron. In addition, B has a high affinity to the soil, unlike Cl. Therefore B will have a greater tendency to accumulate in the soil. It is recommended that the soil be monitored periodically for B accumulation in areas where the irrigation water supply approached or exceeds 0.7 mg/L. This is particularly important in areas planted with trees and vines.

In summary, because boron concentrations in water sources have reduced over the years to low levels, presumably due to the ban on use of boron-based detergents (Harza, 1996), specific-ion toxicity related to boron is not a major concern but routine monitoring of water supplies as well as soils is recommended.

III.3.3. Sodium (Na) Toxicity

Sodium (Na) is often suggested as an ion that produces specific ion injury. Although clearly an ion of concern, there are no clear-cut guidelines indicating concentrations in irrigation water that produce injury. This is due to the fact that numerous factors affect Na accumulation in leaves. Most of the Na tends to concentrate in stems and woody tissue and Na uptake by roots and transport within the plant are affected by the level of calcium in the soil water, and its ratio relative to Na (Läuchli and Epstein, 1990). Then after three or four years, the conversion of sapwood to heartwood apparently releases the accumulated Na which is then transported to leaves causing leaf burn (Maas and Grattan, 1999).

The concentration of Na increases proportionally more than Ca as this water is degraded from that in KAC to KTR. This may be due to detergents or NaCl-based water softeners used by residents in the city of Amman. Some citrus and stone fruit trees have developed injury using water as low as 115 mg/L Na but injury does not always develop at this low concentration. Also there are differences among rootstocks in their ability to absorb and retain Na.

As indicated above, sodium toxicity is not only associated with water high in Na but is associated with high sodium to calcium ratios as well. In light of the low Na concentrations and low SAR's, it is unlikely that Na-toxicity will occur under irrigation practices that do not wet the leaves and that have adequate drainage. There is potential for Na toxicity due to foliar absorption should sprinkler irrigation occur. However because little or no sprinkler occurs in the Jordan Valley, a large scale problem should not occur.

A summary table is provided below that indicates the relative risk among different "plant toxicity" parameters (Table 5). Chloride is the major ion of concern. It can produce injury on a number of sensitive tree crops. The ranking in this table is based on the assumptions of good water management, soils with adequate leaching and long-term water use.

Table 5. Relative risk of Cl, Na and B in KAC and KTR water (based on 1994-99 data and 1999 data alone) in developing leaf injury.

Plant toxicity parameter	KAC	KTR(1994-99)	KTR (99)
Chloride (Cl)	low	mild	moderate
Sodium (Na)	low	low	low
Boron (B)	low	low	low

III.4. Accumulation of Trace Elements

Irrigation with recycled water raises the concern regarding the accumulation of trace elements in the crop and soil. Trace elements occur in almost all water supplies but at very low concentrations with most less than 100 µg/L. Surface water normally contains lower concentrations than groundwater. Usually irrigation waters do not need to be checked for trace elements unless there is wastewater from human's activities present, particularly mining and industrial discharges.

In most cases, trace elements accumulate in plants and soils, and the main concern is their long-term buildup in the soil, which could cause phytotoxicity in plants or result in human or animal health hazards. This accumulation takes place regardless of the management used.

The suitability of recycled water for irrigation was determined using data at the KTR outlet (Table 1) using two standards. The Jordanian standard for reuse of treated domestic wastewater is provided in table 6. This set of standards is provided based on different crop categories and for the discharge into streams and wadies. In addition, the recommended standard for maximum allowable concentrations of trace elements in irrigation water as defined by the Food and Agricultural Organization of the United Nations (Ayers and Westcot, 1985) and Pratt and Suarez (1990) in Table 7.

Table 6. Jordanian standard 893/1995 for reuse of treated domestic wastewater (mg/L).

Parameter	Cooked Vegetables (1)	Fruit & Forestry Trees, Crops & Indust. Products	Discharge to streams, wadis & Reservoirs	Irrigation of Fodder Crops
Al	5	5	5	5
As	0.1	0.1	0.05	0.1
Be	0.1	0.1	0.1	0.1
Cu	0.2	0.2	0.2	0.2
F	1	1	1	1
Fe	5	5	2	5
Li	2.5	5	1	5
Mn	0.2	0.2	0.2	0.2
Ni	0.2	0.2	0.2	0.2
Pb	5	5	0.1	5
Se	0.02	0.02	0.02	0.02
Cd	0.01	0.01	0.01	0.01
Zn	2	2	15	2
Cr	0.1	0.1	0.05	0.1
Hg	0.001	0.001	0.001	0.001
V	0.1	0.1	0.1	0.1
Co	0.05	0.05	0.05	0.05
Mo	0.01	0.01	0.01	0.01

(1): Values for trace elements and heavy metals are calculated based on the quantity of water of 1000mm/yr. These concentrations should be reduced in case more irrigation water is used.

Table 7. Recommended maximum allowable concentrations of trace elements in irrigation water for long-term protection of plants and animals.

Element		Recommended Maximum Concentration[2] (mg/l)	Remarks
Al	Aluminum	5.0	Toxic in acid soils (pH < 5.5), but in alkaline soils (pH >7) like those in the Jordan valley the toxic Al exists at very low levels.
As	Arsenic	0.10	Crops more sensitive in sandy soils. Crops will tolerate higher concentrations in fine-textured soils
Be	Beryllium	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cd	Cadmium	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co	Cobalt	0.05	A concentration of 0.10 is near the toxic threshold for many plants in nutrient solutions. Toxicity varies depending on type of crop and soil chemistry.
Cr	Chromium	0.10	Toxicity observed at 120 kg/ha and depends on the form of Cr existing in the water and soil.
Cu	Copper	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions. Likely to be tightly adsorbed onto soils and thus unavailable for plant uptake.
F	Fluoride	1.0	Inactivated by neutral and alkaline soils like those in the Jordan valley therefore a higher value can be tolerated than indicated here.
Fe	Iron	5.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Li	Lithium	2.5	Tolerated by most crops up to 5 mg/l: mobile in soil. Toxic to citrus at low concentrations (i.e. 0.075 mg/l).
Mn	Manganese	0.20	Toxic to a number of crops at a few tenths to a few mg/l, but usually only in acid soils. Mn in the soil solution will be low such that conc in the irrigation water is relatively unimportant.
Mo	Molybdenum	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum (i.e. molybdate).
Ni	Nickel	0.20	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH like those in the Jordan valley.
Pb	Lead	5.0	Can inhibit cell growth at very high concentrations. Adsorbed tightly to soils. Pb more likely to get into plant by foliar absorption.
Se	Selenium	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations. Sulfate reduces uptake of selenate.

Ti	Titanium	----	Effectively excluded by plants; specific tolerance unknown.
V	Vanadium	0.10	Toxic to many plants at relatively low concentrations
Zn	Zinc	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH >6.0 and in fine textured or organic soils like those in the Jordan valley.

[1]: Adapted from Ayers and Westcot (1985) and Pratt and Suarez (1990).
[2]: The maximum concentration is based on a water application rate, which is consistent with good irrigation practices (1000 mm/year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 1000 mm/year. The values given are for water used on a continuous basis at one site.

The data on trace element concentrations in the KTR water does not present a potential to limit crop production or limit short or long-term productivity because of trace element accumulation. Nevertheless there are four elements particularly worthy of discussion.

The Mn concentration at the KTR outlet is very close to the maximum allowable concentration for the sustained use of water for irrigation. Because of the alkaline nature of the soils, it is unlikely that this element will pose a problem in the future but should be included in periodic monitoring both in growers fields (top 10 cm) and strategic sites along the KTR network. Another concern is that the background concentrations of Mn in Jordanian soils tend to be high (Elham Abu-Aishe, personal communication).

The concentrations of Mo and V are also high relative to the recommended guidelines . The uptake of molybdate and perhaps vanadate is greatly reduced in the presence of sulfate, a compound abundant in Jordanian soils. Nevertheless molybdate is mobile in alkaline soils and is readily taken up by forages. It is also unlikely that these elements will pose a long-term restriction of the use of this water for irrigation but monitoring is suggested for Mo along key sites in the conveyance system. It is also recommended to monitor forages for Mo accumulation.

The final element of concern is lithium. Although the guidelines for Li are high (2.5-5 mg/L) Li has been found to be extremely sensitive to citrus at concentrations as low as 0.075 mg/l. Because of the mobility and potential availability of this element, it is recommended that routine sampling protocol be established that samples irrigation water supplies, Li concentrations in the crop rootzone and plant tissue concentrations should citrus be irrigated with this water.

In summary, it is unlikely that trace elements or heavy metals leaving KTR will not restrict irrigated agriculture. Nevertheless particular attention should be directed towards Mn, Mo, V and Li in future monitoring programs both in regards to water, soil and plant analyses.

III.5. Potential Risk to Public Health

The primary constraint to any project proposing to use recycled water is public health. Wastewater, particularly domestic wastewater, contains pathogens that pose a threat of disease when not managed properly. The primary objective of any recycled water use project must be to minimize or eliminate potential health risks. This objective should also be the main goal of the Jordanian government in all projects regarding use of recycled water within the Jordan valley.

Guidelines for the quality of recycled water used for irrigation have focused on effluent standards at the wastewater treatment plant rather than the quality at the point of use. The most recent guidelines (Table 8) were adopted by World Health Organization (WHO) in 1989 after an extensive epidemiological review. These new guidelines are stricter concerning the need to reduce helminth egg concentrations throughout the entire cropping systems. The purpose of the new guidelines was to increase the level of protection for agricultural workers who are at high risk from intestinal nematode infections caused by various helminths. The scientific advisory group to WHO also concluded that no bacterial guideline was needed for the protection of agricultural workers since there was little evidence indicating a risk to such workers from bacteria (Westcot, 1997). Therefore Table 8 is intended as design goals rather than standards requiring routine testing (Pescod, 1992).

Table 8. Recommended microbiological quality guidelines for reuse of treated wastewater for irrigation.[a]

Category	Reuse Condition	Exposed Group	Intestinal nematodes[b] (arithmetic mean no. of eggs per liter[c])	Fecal coliforms (geometric mean no. per 100 ml[c])	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers consumers public	<=1	<=1000[d]	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	<=1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and fecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

a: In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly.
b: *Ascaris* and *Trichuris* species and hookworms.
c: During the irrigation period.
d: A more stringent guideline (<= 200 fecal coliforms/100ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
e: In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.
Source: WHO (1989).

The WHO guidelines were intended to be design goals for planning wastewater treatment plants and not for quality control at the field level. Until these treatment goals can be reliably achieved, FAO (Westcot, 1997) is recommending that the present WHO guidelines be used to control the quality of water used to irrigate vegetable or high-risk crops. This control is best applied at the main irrigation water supply level. The FAO guidelines recommend that the major emphasis be placed on fecal coliform as the main indicator of the safety of the water supply while the original WHO guidelines emphasized both fecal coliform and helminths. It is recommended that both factors be utilized in monitoring and evaluation of the Jordan valley recycled water use areas until safe levels of fecal coliform are consistently achieved. At that time the monitoring should then focus on fecal coliform as the indicator of water safety.

Data on monitoring of the main irrigation water supply for fecal coliform and helminths in KAC was not available. The only known sampling was cited in the Harza report (Harza, 1996) for the KAC prior to mixing with water from the KTR. The average of six monthly samples during the period May to October 1994 was 3,500 MPN/100ml. The monitoring during this period indicates that the KAC north of the confluence exceeds the WHO guidelines (WHO, 1989) for unrestricted irrigation. The source of this contamination is unknown but should be located and steps taken to eliminate the discharges causing these exceeded levels.

The other potential source of contamination to the KAC would be releases from KTR. Monitoring of the release from KTR has been conducted by the Royal Scientific Society (RSS, 1995) for JVA. The microbiological data for the period February 1995 to January 1996 are shown in Table 9. During this period, nematodes eggs per liter (helminths) were zero indicating that the wastewater treatment ponds and the retention time in KTR are sufficient to remove nematode eggs to a level that would allow unrestricted irrigation in the Jordan valley. However should the retention time drop in the future as the flow of water entering the reservoir increases, nematode egg counts should be continued to make sure that a problem does not arise.

Table 9. Microbial analysis of the water collected at various locations during May – October, 1994. Values are monthly averages.

Site	Total Heterotrophic Bacterial Counts (CFU/ml)	Total Coliform Counts (MPN/100ml)	Fecal Coliform Counts (MPN/100ml)
Effluent of As-Samra WSP	3.99×10^6	4.77×10^3	3.41×10^3
23 km before KTD	3.92×10^6	2.94×10^4	4.72×10^4
KTD Reservoir	3.46×10^4	2.43×10^3	2.67×10^2
KTD Outfall	3.72×10^4	4.74×10^2	4.31×10^1
Tal Al-Thahab	5.03×10^4	4.0×10^3	3.53×10^2
Abu Zeighan	3.54×10^5	3.0×10^3	3.41×10^3
Yarmouk River (KAC before mixing)	3.93×10^4	5.26×10^3	3.44×10^3
KAC after mixing	4.17×10^5	2.64×10^4	7.88×10^4
KAC DA's 22,23	1.58×10^5	4.53×10^4	4.5×10^4
KAC DA's 24,25	4.22×10^5	2.97×10^4	4.10×10^4
KAC DA's 26,27	3.86×10^5	3.9×10^4	3.82×10^3

[1] Colony Forming Unit /ml.
Source: WQIC-USAID (1995)

Downstream of the KTR outlet the data in Table 9 indicate that secondary contamination of the irrigation supply system is occurring. Downstream fecal coliform concentrations are increasing after the KTR releases. During the six-month monitoring period, KTR outflows averaged 43 MPN/100ml fecal coliform, while downstream after mixing with KAC water, fecal coliform levels increased to 4,000 to 8,000 MPN/100ml.

The microbiological quality of the irrigation water is variable and at times of marginal quality for unrestricted irrigation practices. At the present time, quality is such that safe production can be achieved through the use of drip irrigation but restrictions on other types of irrigation systems may be needed to meet international standards. Monitoring and regulating the way water is applied is likely to be more difficult than attempting to correct the present contamination problems. The present level of secondary contamination in the irrigation supply system is not widespread and could probably be corrected. Such an effort would provide water that is fit for unrestricted use based on present guidelines recommended by FAO (Westcot, 1997) which are based on the present WHO guidelines for design of wastewater treatment plants (WHO, 1989).

Based on the data available it seems that unrestricted irrigation use of the KTR water can be accomplished and is much more attractive than restricting the types of crops that are grown in the Middle and Karameh directorates. However, present conditions produce a water of marginal quality which raises concerns for public health and safety. The concern can quickly grow to a lack of public confidence, both nationally and internationally, if the Jordanian Government is not proactive in monitoring and reducing present level of contamination.

If the water in the KAC at all points along the system can consistently meet WHO standards regarding TFCC, then it is possible that KTR and KAC water can be used for unrestricted use in agriculture. A few point sources may be the primary cause of secondary contamination. Therefore a thorough sanitary survey of the JVA distribution system needs to be conducted to identify sources of contamination, and develop a plan to remove them. This will allow JVA to then concentrate its efforts on obtaining a high quality supply from WAJ and delivering water - their two main functions. Therefore TFCC will need to be monitored at a number of points along the water conveyance system not only at existing points but additional points that will provide valuable information regarding sources of secondary contamination sites.

III.6. Water Infiltration Hazard

The infiltration rate into the soil can be affected by the quality of the irrigation water applied. The two most common water quality factors that influence the infiltration rate are the salinity of the water (ECw) and its sodium content relative to the magnesium and calcium content (i.e. sodium adsorption ratio, SAR). An infiltration problem related to water quality, in most cases, occurs in the surface few centimeters of the soil and is linked to the structural stability of this surface layer and how irrigation water quality affects the calcium content of the soil relative to that of sodium.

Water infiltration is generally improved within a given soil as the ECw increases and SAR decreases (Ayers and Westcot, 1985). Figure 2 illustrates that given both the ECw and SAR of the water, whether an infiltration problem is likely to occur. This figure is used to estimate the potential infiltration problem that may be encountered

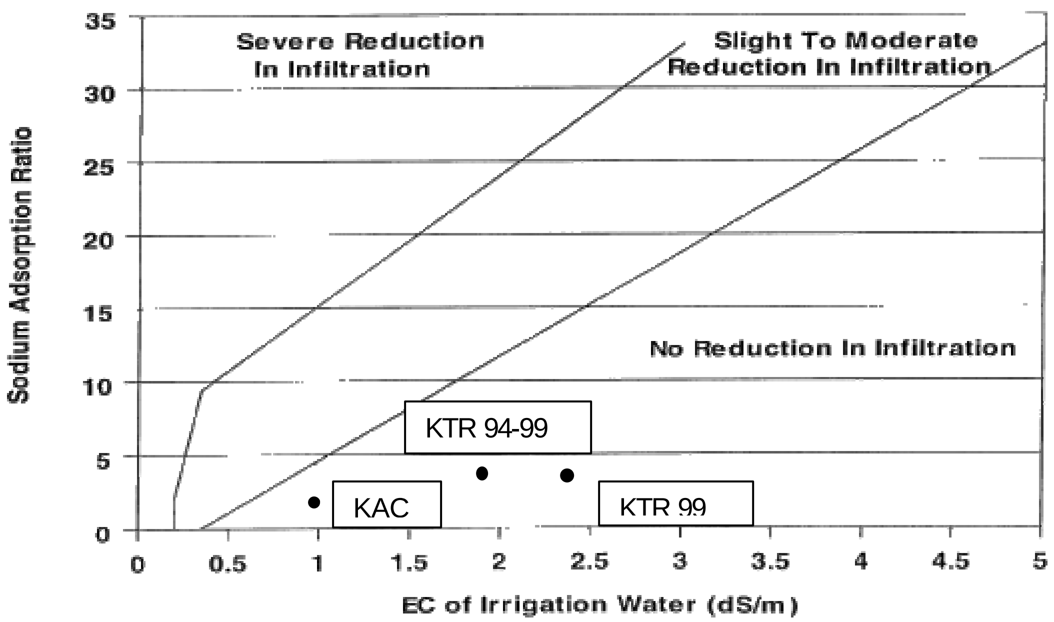

Figure 2. Relative rates in water infiltration as influenced by both the salinity (ECw) and sodium adsorption ratio (SAR) of the irrigation water.

in the Jordan valley should KAC or KTR be used for irrigation.

The ECw and SAR of the KAC water are1.0 dS/m and 2, respectively. This places the water in the "No reduction in Infiltration Rate" zone. Therefore it is unlikely that this water will pose a potential infiltration problem.

The ECw and SAR of the KTR water is 1.9 dS/m (2.4 dS/m based on 1999 data alone) and 4, respectively. The slight increase in SAR reflects a greater proportional increase in the Na concentration in KTR vs KAC than for Ca and Mg. Nevertheless, the quality of KTR water falls again into the "No Reduction in Infiltration Rate" zone.

Therefore the permeability hazard using the FAO guidelines (Ayers and Westcot, 1995) shows a low potential due to the combination of low SAR and elevated water salinity levels (ECw). The low SAR is probably due to the elevated calcium level in the natural waters of Jordan. This same characteristic was found in water from the King Talal Reservoir. The soil conditions in the Jordan Valley, many of which have a strong calcium carbonate characteristic, would also work to reduce the permeability hazard.

III.7. Crop Nutrient Requirement (N and P)

The nutrients in KTR water provide a benefit when used to irrigate crops. The two most prevalent nutrients in water are nitrogen and phosphorus, both of which are major nutrients for the crop. Most irrigation waters from natural sources contain low concentrations of these two nutrients. Recycled water on the other hand can contain significant quantities of nitrogen and phosphorus. Where recycled water is being used, nutrient management must be considered as part of the irrigation management. In the case of nitrogen, the plant needs significant quantities in the early stages of growth but it is much less beneficial towards maturity. Because the application of these nutrients occurs with the application of the water, there is little ability to regulate the application to meet crop needs on a temporal basis. During the latter periods, nitrogen may even stimulate excessive vegetative growth, may delay maturity or reduce crop quality. A similar reaction would not be expected with phosphorus because of the lower concentrations in the water.

III.7.1. Nitrogen.

Nitrogen is needed by all plants in significant quantities and is a major component of many domestic wastewaters. At the KTR outlet, the total N is between 26-30 mg/L most of which is in the ammonium (NH_4) form. Therefore there is a significant load of total nitrogen that leaves KTR and is carried through the irrigation distribution system. The data is not adequate however to evaluate the loads that will be received by any specific area as it will depend on the time of year and the dilution or mixing of irrigation supplies that occur. In the future when KTR water begins to make up a more significant portion of the total flow, the nitrogen levels will increase in importance. Because of this, a monitoring program that focuses on total nitrogen needs to be established. It is only with having quality data that management decisions can be made.

Because nitrogen is a fertilizer resource and water use can be measured, an approximation of the Kg/dn of nitrogen could be estimated or quantified. For example, if the total nitrogen concentration in the irrigation supply water was 50 mg/l, this would input 0.15 - .25 Kg (N)/dn/day which is a significant quantity of nitrogen. Therefore fertilizer application rates should be adjusted downward to account for this supplemental addition. In some cases, KTR water may account of all the N needs particularly if one accounts for residual N stored in the crop rootzone.

Nitrogen is not always beneficial to crops. For example high concentrations late in the season can adversely affect fruit quality, cause unnecessary vegetative growth and/or delay maturity. Examples include excessive vegetative growth and reduced soluble solids in tomato, reduced sugar concentration in sugarbeet, delayed maturation rates for fruits of tomato and grape, and reduce fruit set in olive (Elham Abu-Aishe, JVA, personal communication).

III.7.2. Phosphorus

Phosphorus is required by all plants and is found in many wastewater effluents. The average phosphorus concentration entering the KTR ranges from 5-7 mg/l as total phosphorus (Harza, 1996 and USBR, 1998). This concentration is consistent with concentrations found in other wastewaters worldwide (Asano and Pettygrove 1985, Pescod and Arar 1988 and Pescod 1992).

Total phosphorus at the level found in KTR will act as a plant nutrient but is unlikely to cause excess phosphorus availability to the plant. With the calcareous soils of the Jordan valley, phosphorus in the KTR water delivered for irrigation should not cause a problem. Although there is a benefit from this plant nutrient, it is not at such a level that it would replace the need for supplemental fertilization.

Not only are N and P valuable plant nutrients, but recycled water use can have positive environmental benefits. With proper reduction in N fertilizer applications, the concentration of both N and P in the drainage water could actually be decreased which will benefit the quality of the receiving waters (i.e. Jordan river and the Dead Sea). This point was also eluded to in the report by Bahri (1997).

In summary, N and P should be considered as nutrient resources. Therefore planning is recommended at the farm level to adjust fertilizer requirements to account for this supplemental supply of nitrogen. Caution is advised for crops that are susceptible to reduced quality due to high N late in the season.

III.8. Clogging of Drip Emitters (TSS, N, P, pH, HCO_3)

Certain parameters are important since they affect maintenance of the irrigation conveyance system or drip irrigation systems. Parameters that are of greatest concern are pH, HCO_3, biological sources (e.g. alage and bacterial slimes) and total suspended solids (TSS). These parameters can clog drip irrigation systems.

III.8.1. Algae formation in Canals and Holding ponds

Degraded water quality affects the quality and maintenance of the irrigation conveyance systems (see Forward, 1999). There are a number of water quality parameters that can affect on-farm management and maintenance of both irrigation and water conveyance systems. Algae formation is particularly problematic both in irrigation canals and irrigation water supplies that contain KTR water. The primary problem that this presents is clogging of drip irrigation systems.

The combination of both nitrogen and phosphorus in the irrigation water supplies containing KTR water are the main contributors to algae formation. Total nitrogen is 26-30 mg/L which is 7 times higher that in the KAC water (Table 1). Total phosphorus in the KTR water is 5-7 mg/L which is 15 times higher than that in KAC. These two nutrients provide the perfect media for eutrophic conditions.

It is likely that phosphorus is the key nutrient in the eutrophic conditions of KTR. The United States Bureau of Reclamation (1998), after review of the KTR, has concluded that total phosphorus in the reservoir will continue to increase as it is estimated that about 50% of the total phosphorus entering the reservoir is being retained in the reservoir. The Bureau estimates that total phosphorus entering the reservoir is the primary reason that KTR is eutrophic. The estimate that nutrient loads, in particular total phosphorus, would have to be reduced 100 - 200 times to result in an improvement in the eutrophic condition of the reservoir. It is expected that phosphorus will continue to enter the reservoir at greater than 0.1 mg/l thus causing the reservoir to remain hypereutrophic. This condition will result in the reservoir having an algae problem for the foreseeable future.

The algae problem will cause maintenance problems in the downstream irrigation system and continue to result in esthetic problems in and near the KTR and the downstream distribution system. Chlorination may be an effective means to periodically control algae and avoid the build-up of bacterial slimes within the system (Hanson et al. 1994).

III.8.2. Suspended Solids

Suspended solids such as sediment and organic material must be removed from the water before it enters the drip irrigation system. Sediments in the irrigation water may vary considerably in different parts of the valley and can vary dramatically over time. For example sediment loads may be particularly high just after it rained but these will be found in both KAC and KTR water supplies.

Sand and media filters are used by farmers in the Jordan valley to remove such material provided that the irrigation water is not overloaded. The on-farm filtration units are not designed to remove the heavy levels of organic and inorganic contaminants often delivered in the water from the JVA (Hagan and Taha, 1997). As a result, back-flushing of the filtration system becomes more and more frequent and burdensome to the point where some growers remove their screen filters (Hagan, 1998, personal communication). This action proves fatal to drip irrigation system and have to be replaced in a relatively short period of time. Studies in the Jordan valley have shown that about 75% of all farms experience significant plugging problems beginning the second year of lateral line use (Hagan and Taha, 1997). In areas that are subjected to frequent and excessive loads of suspended material, it is recommended that a central water conditioning facility be installed at the start of the delivery pipeline (Hagan and Taha, 1997). Some filtration systems have already been installed but with little success. Below are guidelines provided by Pescod (1992) regarding suspended solid contents and pH levels and their likeliness to present management-related problems (Table 10).

Table 10. Physical water quality parameters in relation to their likeliness to present management-related problems.

Water Quality Constituent	Degree of Restriction on Use		
	None	Slight-Moderate	Severe
Suspended solids (mg/L)	< 50	50-100	>100
pH	< 7.0	7.0 - 8.0	> 8.0

Source: Pescod (1992)

Data in table 1 indicate that the average total suspended solids (TSS) is actually higher in KAC water than that in KTR. The 1997-99 average for TSS in KAC is 56 mg/L. The guidelines in table 10 suggest that this will pose a slight to moderate restriction of its use. On the other hand, TSS leaving the KTR was on the average 20 mg/L indicating no restriction on use. Lower TSS in KTR may be related to KTR serving as a settling basin. Regardless of relatively low TSS at the KTR this benefit is then lost when this water is reintroduced into the KAC at the confluence.

III.8.3. Chemical Clogging of Emitters

Chemical clogging of drip emitters is usually associated with lime ($CaCO_3$) and phosphates ($Ca_3\ (PO_4)_2$). The tendency of a water to cause calcium precipitation can be predicted although there is no proven practical method to evaluate how serious the problem will be since it depends upon many factors such as temperature and pH. A first approximation of calcium precipitation can be made using the saturation index of Langelier as described in the FAO guidelines (Ayers and Westcot, 1985). This index simply says that upon reaching the calcium saturation point in the presence of bicarbonate, lime will precipitate from the solution.

pH is an indicator of the acidity or basicity of a water. The normal pH range for irrigation water is from 6.5 to 8.4. A pH outside this range is seldom a problem by itself and usually indicates the potential for a nutritional imbalance or that the water may contain a toxic ion. The greatest hazard of an abnormal pH in irrigation water is the impact on irrigation equipment. High pH may be incompatible with certain fertilizers injected into drip irrigation systems and facilitate precipitation of certain chemicals at the orifice of the emitter which can clog the system.

The pH of the water released from KTR is 7.8 to 7.9 (Table 1). This is a bit lower than that in the KAC (8.2-8.4). According to the guidelines in table 10, KTR and KAC water fall into slight-moderate restriction and severe restriction on use, respectively. The high pH of these waters present a potential to cause precipitation of lime on drip emitters although a more through evaluation is needed to determine if this is a real potential.

Should there be a potential problem with chemical precipitation, corrective actions can be taken. The most effective method of preventing problems caused by precipitation of calcium carbonate is to control the pH at the farm level or to clean the system periodically with an acid in order to prevent deposits building up to levels where clogging might occur. The most common practice is to inject acid into the system periodically. Some practical guidelines for acid injection are provided in Hanson et al. (1994).

In summary, clogging of drip irrigation systems is likely to continue to be a problem that must be managed. Chemical precipitation and sediments will be problematic regardless of the water source. Biological clogging agents such as algae or bacterial slimes will be problematic with the reuse of KTR water. It is recommended therefore that the Jordan Government seek technical assistance in determine the extent of emitter clogging problems that are likely to occur with use of the KTR water and identify a feasible and economically attractive means of correcting this problem.

IV. ADDITIONAL CONSIDERATIONS WHEN IMPLEMENTING REUSE

IV.1. Need for Extension Education

Special care needs to be taken to maintain a favorable environment in the crop root zone when irrigating with poor quality water. A shift from low to higher salinity water requires a higher level of operational and management skills for JVA and the farmer. The skill level of the farmer needs to be upgraded in order to utilize water supplies of higher salinity successfully. The grower needs to know crop water requirements, basic principles on irrigation management, basic principles related to salinization and salinity control, and carefully monitor the soils for salinity build-up and identify poorly drained areas.

Because higher salinity water removes a portion of the farmer's margin of safety, adequate training is needed to ensure they have the ability to manage this degraded water as effectively as possible. A mistake in salinity management may cause a yield loss, crop loss or, in a worst-case scenario, the loss of production capability until reclamation can be achieved. Because the Jordan valley farmers do not have extensive capital backing, a loss at any level could put the farmer out of business. The success of the farmer is now closely tied to the quality of the water.

Currently JVA produces bulletins periodically directed towards the grower to help inform them of important conditions or changes in water quality. Unfortunately these rarely make it to the grower and if they did, the grower may not have the skills to interpret such information.

Extension education will help train JVA staff and growers to upgrade their irrigation management skills. The Ministry should review effective "Extension Education" programs throughout the world preferably in collaboration with the University of Jordan and NCARTT and consider modeling such a program within the Jordan Valley. The Irrigation Water Policy; Paper No. 2 (1998) encourages such an activity.

To be most effective, it would require individuals with graduate level education to be located not only in the field but also on the University campus. This group is not intended to replace existing irrigation consultants or the Irrigation Advisory Service (IAS) but rather to work with them and educate them so that their skills remain strong and current.

IV.2. Opportunities for Increasing the Salt Tolerance of Crops

It would be desirable if the salt tolerance of existing crops could be improved substantially allowing them to be grown successfully in saline environments. Unfortunately efforts have not been very successful. For example, during 1980-1995, more than 300 papers were published per year on the mechanisms of salt tolerance. Nevertheless only a few new varieties have been released with only slight improvement in tolerance from their parental lines (Flowers and Yeo, 1995). Therefore it would be too optimistic to rely on substantial improvements in salt-tolerance of currently popular crops in the near future despite recent advances in genetic research.

IV.3. Introduction of New Salt Tolerant Forages

There are a number of salt-tolerant forages (and other species grown as forages) that successfully be grown in the 14 km area using very saline water (ECw of > 4 dS/m) while at the same time producing a valuable source of fodder. Currently, a number of animals in the Jordan valley are returned from the market because they do not meet certain quality standards (Mohamed Yussef Hamdan, grower, personal communication). For example, warm-season C4 grasses like ***Cynodon***, *Paspalum*, and ***Distichlis*** species tolerate high temperatures and salinity and grow in the spring and summer (Oster et al., 1999). Although some studies have been conducted that address forage quality in salt-stressed land (e.g Atiz-ur-Rehman et al. 1999), a considerable amount of additional research in this area is needed . Currently, field studies and field demonstrations are underway in California's San Joaquin valley to test the feasibility of a few salt-tolerant forages and forage cropping strategies (S. Benes, 2000, personal communication; Oster et al., 1999) for irrigation with saline-sodic water. Some promising species include bermudagrass, saltgrass, siltgrass, alkali sacaton, Jose wheatgrass, cordgrass, creeping wild rye, "salado" alfalfa, perla, salicornia, purslane and atriplex (Grattan and Oster, 2000; Grieve and Suarez, 1997, Marcum, 1999, Shannon et al. 1998). Their actual suitability will depend upon their production potential under saline conditions and their resulting forage quality.

These potential forages should only be considered using water that would other wise be deemed unsuitable for irrigation and would normally be discharged to the Jordan river and the Dead Sea.

IV.4. Transfers in Land Ownership and Management

In most arid and semi-arid regions of the world, farmers relying on marginal quality water for irrigation stay in business as long as management skills are sufficient to prevent the long term salinization and loss of production. Often growers with good management skill replace those whose skills are not so good. In such cases, a mechanism needs to be in place that allows for such a transfer in land ownership or land management. It is therefore recommended that policies within JVA change, if necessary, that will make such transfers easy.

IV.5. Monitoring the Irrigation Water Quality within the Conveyance and Distribution System

The MWI needs to continue to monitor the entire conveyance and distribution system network for key water quality parameters. Sampling should be done, at least in regards to key parameters such and EC, on a real-time basis so that growers can be alerted of any abrupt changes in water quality or that proper remediation measures can be taken. Water quality data must also be made readily available for all potential users. A web site should be developed where data recent and historical data are composited.

IV.6. Irrigation Water Requirements.

The irrigation water requirement for the crop is the consumptive crop water use (i.e. cumulative evapotranspiration, ET) plus additional water to account for leaching and irrigation efficiency minus that water it gets from effective rainfall.

Crop water use can be estimated using FAO guidelines (Allen et al, 1998). Use of the program CROPWAT (available from FAO) may also be used to estimate ET. It is important that appropriate crop coefficients (Kc) be used here in the Jordan valley to account for the large spacing between rows. The Kcs may be adjusted by assigning Kc initial as reported in FAO 56 at 10% canopy cover and KC mid at 75% cover. One can then measure the % canopy cover for crops in the Jordan valley at different stages of development and determine the adjusted Kc by interpolation. Any values in excess of 75% would be maximal and thus the same as assigned at 75%.

Much of the Jordan valley is irrigated by drip irrigation however in the Zarqa triangle, drip and furrow each account for about half. Under well operated systems, it is often assumed an irrigation efficiency of 80% for low-pressure systems (i.e. drip and micro-sprinkler) and 70% for furrow. In light of the clogging issues for drip irrigated systems in the Jordan valley, it is likely that the valley average is much less then indicated above. By accounting for these efficiencies, however, the irrigation water requirement was adjusted upward in addition to that to account for different leaching fractions. In many cases the irrigation efficiency factor out weighs the leaching requirement so just the additional water to account for the irrigation efficiency is used. Because the actual irrigation efficiencies will vary quite dramatically from location to location, it is best to assume a “best management” efficiency for planning purposes.

Although the climate of the Jordan Valley falls in the Mediterranean category, there is a difference in both rainfall and evaporative demand in a North-South direction. Rainfall can vary quite dramatically from year to year but the average rainfall in the northern part (north of Deir Alla) exceeds 250 mm/yr whereas the average rainfall in the Karameh part is less than 250 mm/yr. Evaporative demand, on the other hand, far exceeds rainfall and is higher in the south than in the north. The average rainfall in each region was then subtracted from these adjusted values to derive the irrigation water requirement of the crop.

IV.7. Blending Water Supplies vs Keeping them Separate

For a crop production perspective, there is an advantage in having two water supplies available to the grower at a given time rather than blending the two water supplies to achieve some “acceptable” water quality (Grattan and Rhoades, 1990). When two water supplies are kept separate, a “cyclic” irrigation strategy (alternate uses of saline and non-saline water) can be utilized.

Under the cyclic irrigation strategy, water supplies of different qualities are not blended but remain separate. The more saline water is used to irrigate salt-tolerant crops or crops at a more salt-tolerant growth stage. The better quality water is used at all other times. Using this irrigation technique, the soil salinity profile is not in steady state but transient allowing crops that vary in tolerance to be included in the rotation. The "cyclic" strategy keeps the average soil salinity lower especially in the most critical upper portion of the profile and during the early, salt-sensitive growth stage.

The cyclic strategy has many advantages over the blending method since; 1) soil salinity can be lower at certain critical times allowing for more salt-sensitive crops to be included in the rotation 2) a water blending facility is not required 3) water of higher salinity can be used for periodic irrigations than if used for all irrigations and 4) greater use of the combined water supply (saline and non-saline sources) can be achieved (Grattan and Rhoades, 1990).

This irrigation strategy can only be considered in stage offices that have two sources of water quality available for irrigation or if dual sources of water become available in stage offices where they currently do not exist. Despite the agronomic advantages, the logistics of this strategy and economic implications need to be evaluated before it is considered further.

IV.8. Groundwater Quality

A major concern with using KTR water for irrigation is the potential impact of water that is higher in salt and nitrogen concentration, on leaching that may contaminate groundwater supplies. This would be particularly detrimental in cases where the existing aquifer consists of water of high quality. This impact is difficult to assess because no groundwater resource assessment study could be found for the Jordan Valley area that is being considered for recycled water use. This potential threat needs to be evaluated in more detail.

V. SUMMARY OF FINDINGS AND RECOMMENDATIONS

- The quality of KTR water is degraded considerably from that in the KAC north of the confluence. Particular concerns are salts and nutrients (N and P).
- Most of the crops currently grown in the Jordan valley are sensitive or moderately sensitive to salinity. Therefore because of the combination of high salts in KTR water and salt-sensitivity of crops, irrigation management will need to be improved and maintained to optimize production.
- Higher flows of KTR water in the future will help salinity control (i.e. increasing water supplies for leaching) provided the irrigated area does not increase proportionally.
- The salinity content of the KTR is sufficiently high to prevent most crops from achieving their full yield potential. Nevertheless, over 70% of the major crops[3] in the Jordan valley can be grown with KTR water (ECw 1.9 dS/m) and achieve at least 80% of their potential yield. If KTR water increases to 2.4 dS/m, as found in 1999, then only half the crops can be grown to at least 80% yield potential. This may impact the cropping pattern should this water be used undiluted for extended periods. Ultimate cropping patterns will be determined by economics and other factors.
- Water infiltration problems are not likely to be problematic regardless of whether KAC or KTR water is used for irrigation.
- Irrigation delivery systems need to be made more flexible for the grower such that water supplies are available on an “as need” basis. This is particularly necessary for drip irrigation systems requiring frequent irrigations. Broken meters need to be replaced and conveyance system monitored for illegal hookups.
- Sprinkler irrigation is not recommended when using KTR water for irrigation.
- Chloride concentrations in KTR water are sufficiently high to cause injury (in addition to that caused by salt alone) on tree crops (citrus, banana, stone fruits) and possibly grape vines. Where possible, it is recommended to avoid use of this water for irrigation of those crops. Where tree and vine crops are irrigated with KTR water, soils need to be monitored carefully to assume that salts are sufficiently leached from the rootzone. Periodic analysis of leaf tissue would also be useful.
- Boron concentrations have been reduced in the KTR over the years after the ban on B-based detergents. This has substantially improved the quality of water such that B is no longer a threat, provided soils are adequately managed and leached. Boron levels in grower’s fields that irrigate with KTR water need to be checked periodically. Periodic leaf tissue analysis would also be useful.
- All soils that are irrigated with KTR will require natural or artificial drainage. A large fraction of the Jordan valley currently has artificial drains in a number of areas. These drains must be maintained and new drains may be required in the future should perched water tables develop.
- Management strategies need to be developed to periodically leach fields in winter where salinity buildup has occurred. Drip irrigation systems develop characteristic salt accumulation patterns such that a substantial amount of salt

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3 A major crop is defined as having > 1% of the cultivated area for that region.

will accumulate between emitters. Therefore effective leaching methods need to be developed.

- From time to time the KAC at various points has TFCC in excess of WHO standards suggesting secondary contamination is occurring. A thorough investigation is recommended to identify those secondary sources of contamination and develop a plan to remove them.
- Trace elements do not appear to be a limiting factor at this time. Nevertheless it is recommended that a monitoring program of water, soils and plants be sustained in the future.
- Clogging of drip irrigation emitters is a major problem in the Jordan valley. Part of this is due to the high pH nature of the water and sediments that erode from watersheds during winter storms and find their way into wadies and the irrigation system. Biological clogging is also a concern in systems that use KTR water. This is due to the high N and P in the water producing algae formation. It is also likely that bacterial slimes form in the irrigation system and drip laterals.
- Based on the clogging potential due to a number of physical, chemical and biological factors, MWI should evaluate cost effective methods to reduce the problem.
- A permanent Extension education program is needed. This will likely require major institutional changes. The Ministry should review effective “Extension Education programs” throughout the world and consider modeling such a program within the Jordan valley.

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APPENDIX 1

CROPPING PATTERNS BY DIRECTORATE AND STAGE OFFICES

Cropping Pattern for the Karameh Directorate
Cropping Pattern for the Middle Directorate
Cropping Pattern for the Northern Directorate

APPENDIX 1

CROPPING PATTERN FOR THE KARAMEH DIRECTORATE

	SO6		SO9		SO10		TOTAL FOR SO6,SO9,SO10	
CROP	AREA(DUN)	%OF TOTAL	AREA(DUN)	%OF TOTAL	AREA(DUN)	%OF TOTAL	AREA(DUN)	%OF TOTAL
J_Malok	1347	8.76	6760	46.11	0	0.00	8107	22.34
Banana	47	0.31	1365	9.31	4449	71.13	5861	16.15
Melons	10	0.07	4611	31.45	0	0.00	4621	12.73
EggP	2967	19.29	212	1.45	498	7.96	3677	10.13
Citrus	1544	10.04	105	0.72	847	13.54	2496	6.88
Tomato	1517	9.86	90	0.61	0	0.00	1607	4.43
Late_Fruit	784	5.10	0	0.00	361	5.77	1145	3.15
Grapes	927	6.03	5	0.03	14	0.22	946	2.61
G_Beans	447	2.91	450	3.07	32	0.51	929	2.56
Squash	523	3.40	399	2.72	0	0.00	922	2.54
Okra	489	3.18	321	2.19	0	0.00	810	2.23
Lett_Spin	724	4.71	46	0.31	0	0.00	770	2.12
Olives	622	4.04	0	0.00	0	0.00	622	1.71
Peppr	457	2.97	102	0.70	24	0.38	583	1.61
Aut_Fruit	576	3.75	0	0.00	0	0.00	576	1.59
Maize	423	2.75	0	0.00	0	0.00	423	1.17

CROPPING PATTERN FOR THE MIDDLE DIRECTORATE

	SO3		SO4		SO5		SO8		TOTAL FOR SO 3,SO4,SO5,SO8	
CROP	AREA (DUN)	%OF TOTAL	AREA (DUN)	%OF TOTAL	AREA (DUN)	%OF TOTAL	AREA (DUN)	%OF TOTAL	AREA (DUN)	%OF TOTAL
Potato	3654	15.389	1039	5.71	5433	21.64	3442	10.88	13568	13.75
Citrus	4388	18.480	1059	5.82	1924	7.67	5421	17.14	12792	12.96
Tomato	4028	16.964	1198	6.58	1525	6.08	4321	13.66	11072	11.22
Squash	2034	8.566	718	3.95	5275	21.02	822	2.60	8849	8.97
Onion Grld	389	1.638	2494	13.70	558	2.22	3324	10.51	6765	6.86
Cucmbr	2315	9.750	0	0.00	1220	4.86	2433	7.69	5968	6.05
Peppr	1736	7.311	774	4.25	1501	5.98	1028	3.25	5039	5.11
J Malok	222	0.935	2602	14.30	210	0.84	871	2.75	3905	3.96
Wheat & B	1876	7.901	339	1.86	335	1.33	1170	3.70	3720	3.77
BBeans Pe	543	2.287	725	3.98	1911	7.61	366	1.16	3545	3.59
Lett Spin	671	2.826	580	3.19	1	0.00	1984	6.27	3236	3.28
EggP	382	1.609	437	2.40	1820	7.25	587	1.86	3226	3.27
Crucifers	200	0.842	835	4.59	141	0.56	1752	5.54	2928	2.97
G Beans	332	1.398	546	3.00	728	2.90	1222	3.86	2828	2.87
Carrot	0	0.000	2565	14.09	10	0.04	0	0.00	2575	2.61
Maize	225	0.948	1002	5.51	214	0.85	988	3.12	2429	2.46
Late Fruit	230	0.969	96	0.53	400	1.59	725	2.29	1451	1.47

CROPPING PATTERN FOR THE NORTH DIRECTORATE

	SO1		SO2		SO7		TOTAL FOR SO1,SO2,SO7	
CROP	**AREA(DUN)**	**%OF TOTAL**	**AREA(DUN)**	**%OF TOTAL**	**AREA(DUN)**	**%OF TOTAL**	**AREA(DUN)**	**%OF TOTAL**
Citrus	11001	69.76	13270	46.68	16441	47.12	40712	51.48
Tomato	151	0.96	2021	7.11	4464	12.79	6636	8.39
Banana	3160	20.04	256	0.90	1163	3.33	4579	5.79
Potato	63	0.40	2493	8.77	412	1.18	2968	3.75
EggP	46	0.29	2314	8.14	586	1.68	2946	3.73
Wheat & B	268	1.70	20	0.07	2253	6.46	2541	3.21
Squash	36	0.23	1347	4.74	1070	3.07	2453	3.10
J_Malok	0	0.00	992	3.49	1285	3.68	2277	2.88
Okra	61	0.39	1460	5.14	422	1.21	1943	2.46
O_Veg	321	2.04	76	0.27	1022	2.93	1419	1.79
Late_Fruit	118	0.75	797	2.80	386	1.11	1301	1.65
Forage	306	1.94	44	0.15	921	2.64	1271	1.61
BBeans_P	15	0.10	649	2.28	529	1.52	1193	1.51
Crucifers	70	0.44	571	2.01	509	1.46	1150	1.45
Peppr	10	0.06	711	2.50	226	0.65	947	1.20
Lett_Spin	45	0.29	334	1.17	419	1.20	798	1.01

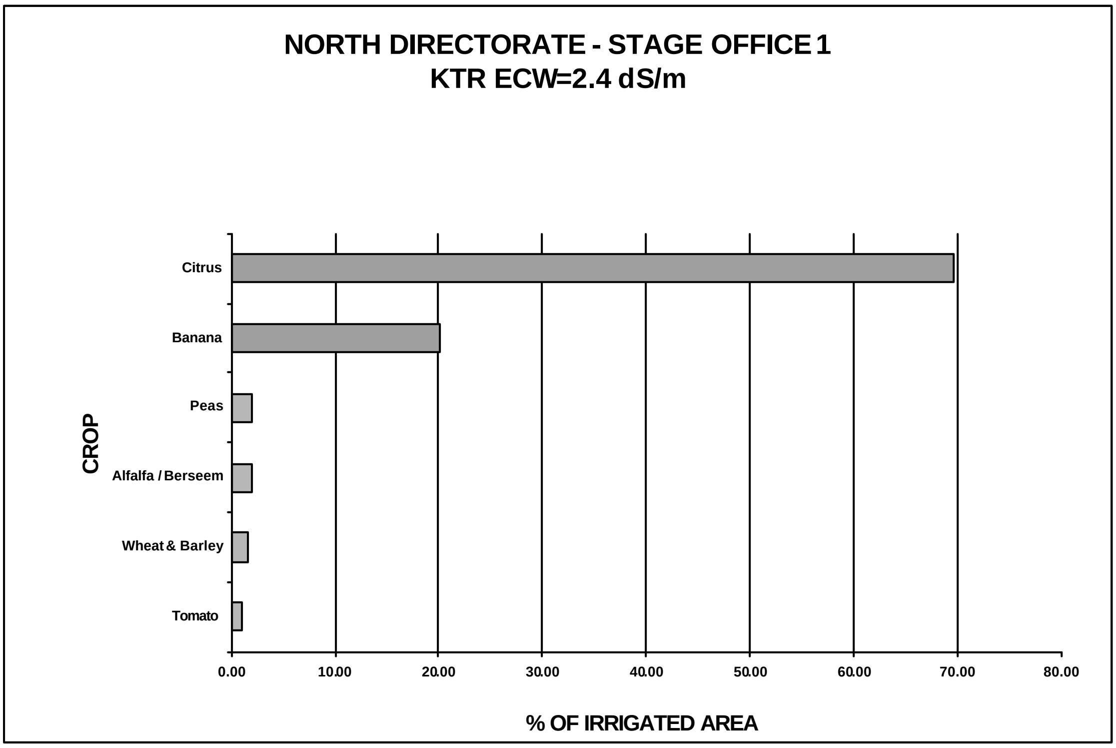
APPENDIX 2

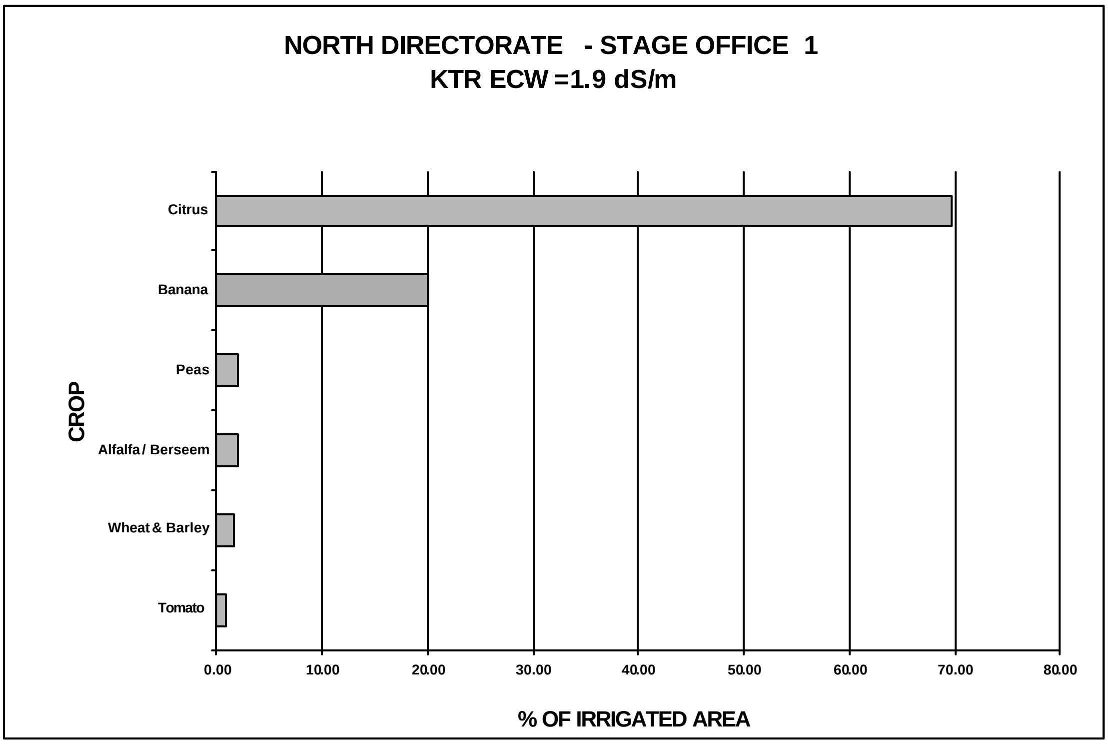
IMPACT OF SALINITY IN EACH STAGE OFFICE

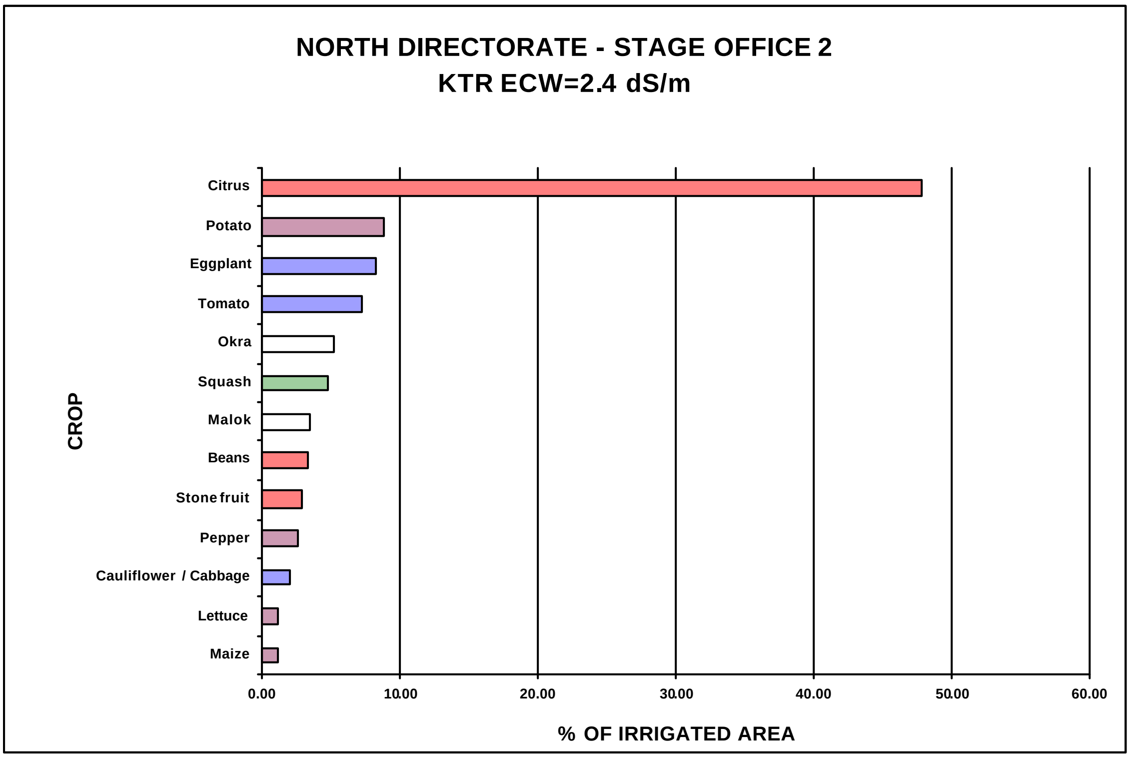
Northern Directorate – Stage Office 1 [Salinity at 2.4-ds/m]
Northern Directorate – Stage Office 1 [Salinity at 1.9-ds/m]
Northern Directorate – Stage Office 2 [Salinity at 2.4-ds/m]
Northern Directorate – Stage Office 2 [Salinity at 1.9-ds/m]
Northern Directorate – Stage Office 7 [Salinity at 2.4-ds/m]
Northern Directorate – Stage Office 7 [Salinity at 1.9-ds/m]

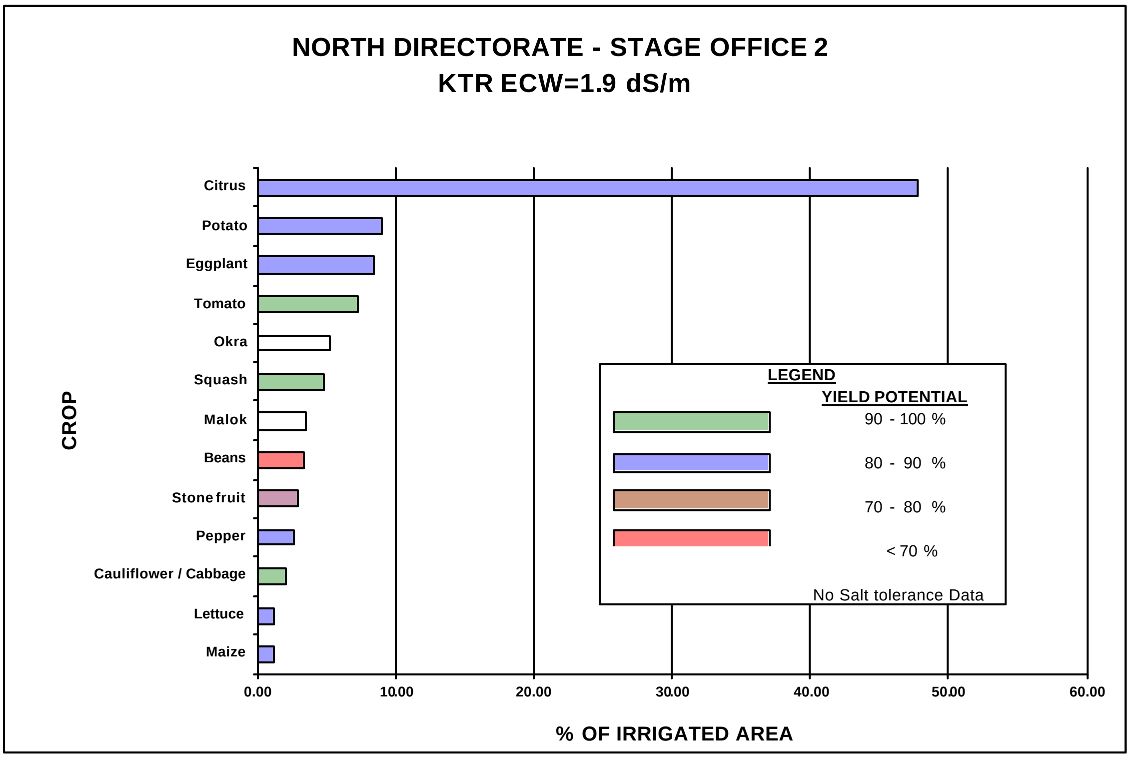
Middle Directorate – Stage Office 3 [Salinity at 2.4-ds/m]
Middle Directorate – Stage Office 3 [Salinity at 1.9-ds/m]
Middle Directorate – Stage Office 4 [Salinity at 2.4-ds/m]
Middle Directorate – Stage Office 4 [Salinity at 1.9-ds/m]
Middle Directorate – Stage Office 5 [Salinity at 2.4-ds/m]
Middle Directorate – Stage Office 5 [Salinity at 1.9-ds/m]
Middle Directorate – Stage Office 8 [Salinity at 2.4-ds/m]
Middle Directorate – Stage Office 8 [Salinity at 1.9-ds/m]

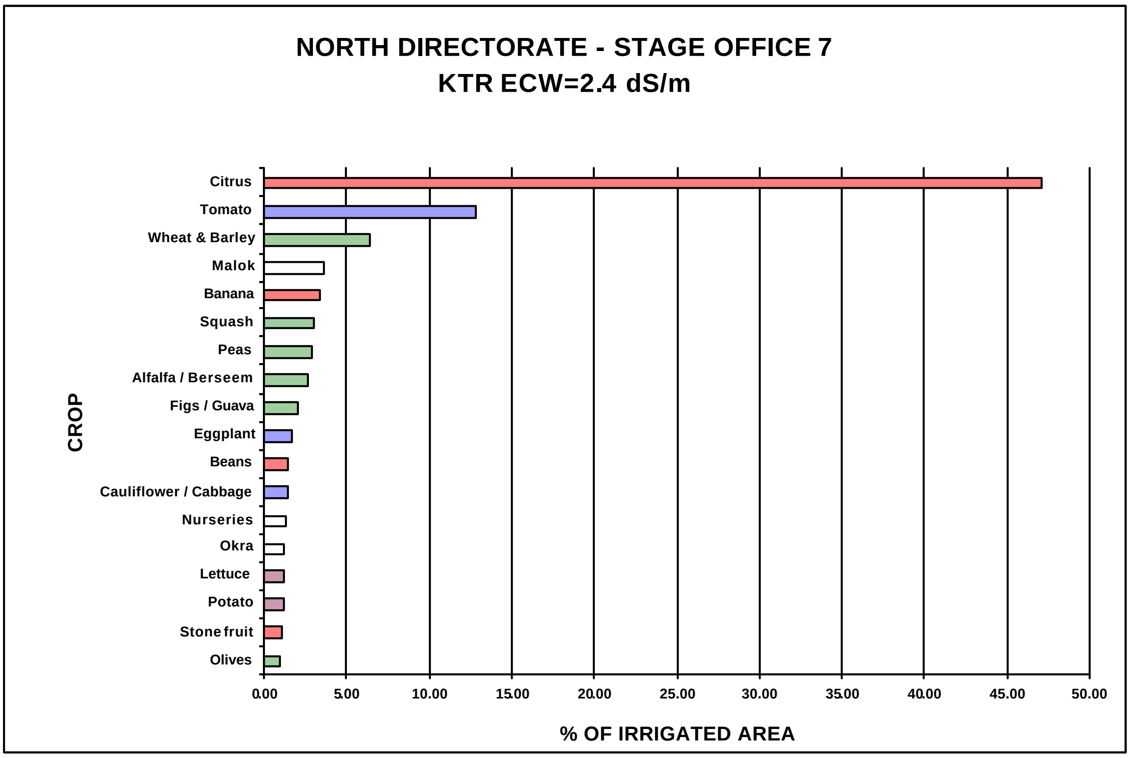
Karameh Directorate – Stage Office 6 [Salinity at 2.4-ds/m]
Karameh Directorate – Stage Office 6 [Salinity at 1.9-ds/m]
Karameh Directorate – Stage Office 9 [Salinity at 2.4-ds/m]
Karameh Directorate – Stage Office 9 [Salinity at 1.9-ds/m]
Karameh Directorate – Stage Office 10 [Salinity at 2.4-ds/m]
Karameh Directorate – Stage Office 10 [Salinity at 1.9-ds/m]

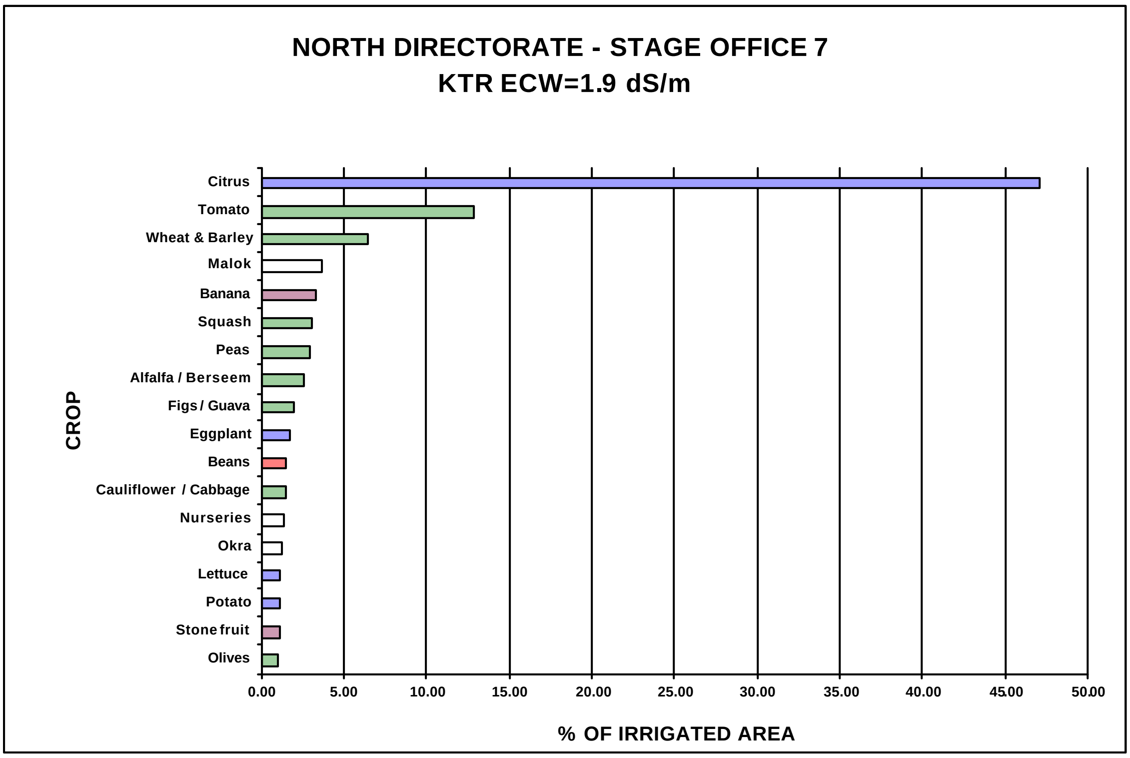

NORTH DIRECTORATE - STAGE OFFICE 1
KTR ECW=2.4 dS/m
CROP
Citrus
Banana
Peas
Alfalfa / Berseem
Wheat & Barley
Tomato
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
% OF IRRIGATED AREA

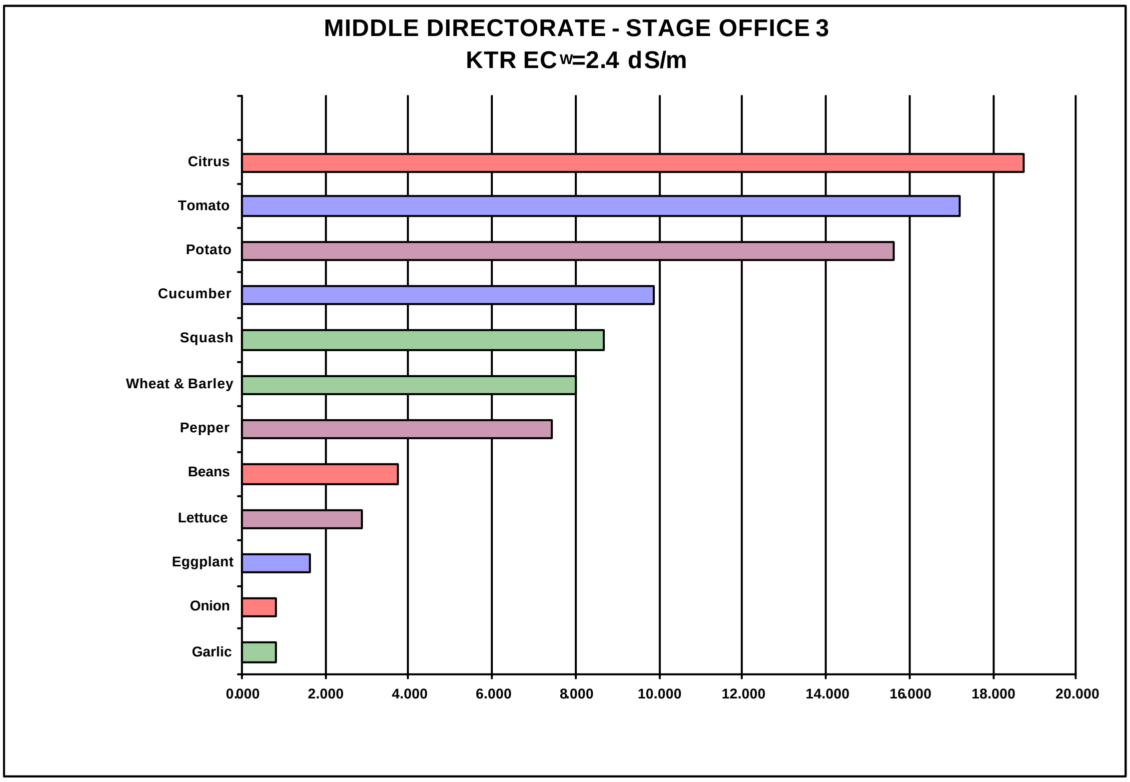

NORTH DIRECTORATE - STAGE OFFICE 1
KTR ECW =1.9 dS/m
CROP
Citrus
Banana
Peas
Alfalfa / Berseem
Wheat & Barley
Tomato
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
% OF IRRIGATED AREA

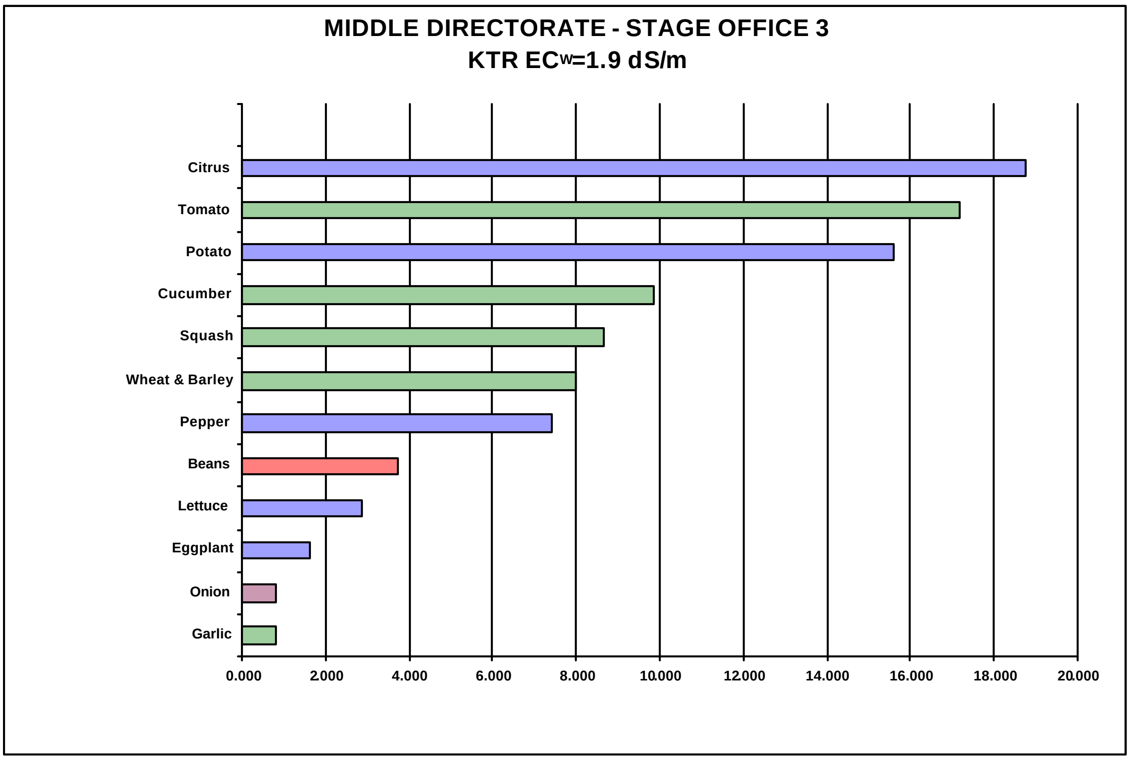

NORTH DIRECTORATE - STAGE OFFICE 2
KTR ECW=2.4 dS/m
CROP
Citrus
Potato
Eggplant
Tomato
Okra
Squash
Malok
Beans
Stone fruit
Pepper
Cauliflower / Cabbage
Lettuce
Maize
0.00
10.00
20.00
30.00
40.00
50.00
60.00
% OF IRRIGATED AREA

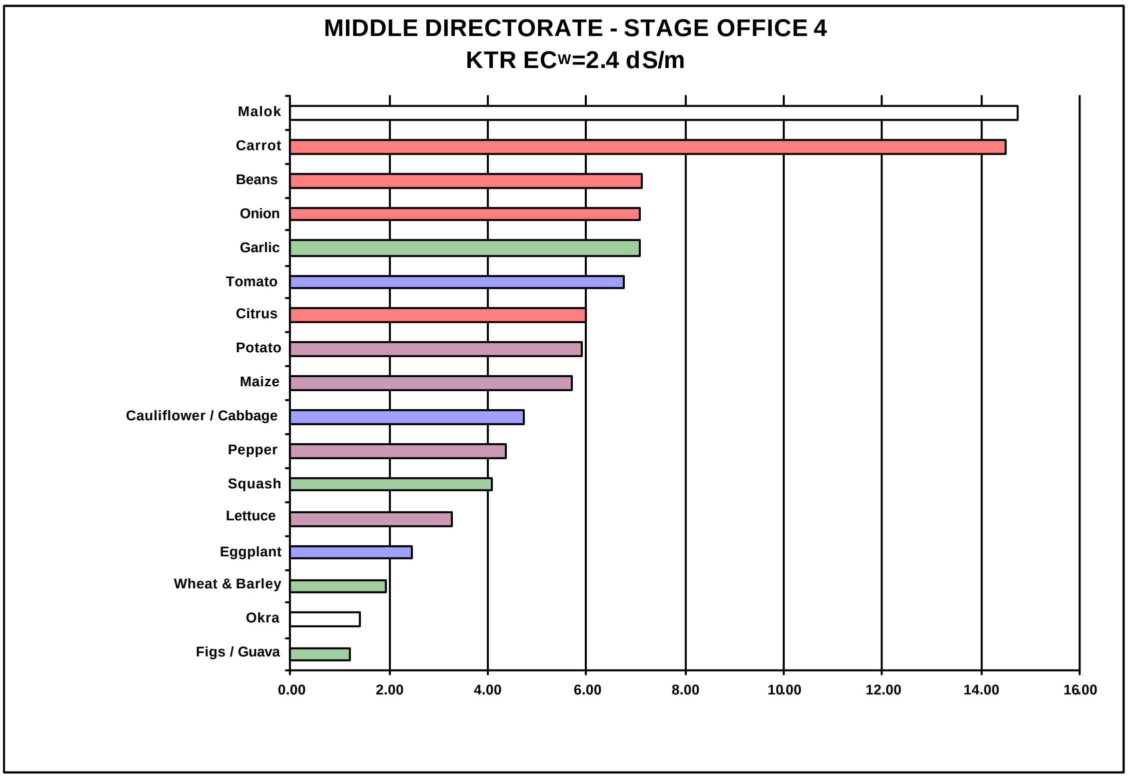

NORTH DIRECTORATE - STAGE OFFICE 2
KTR ECW=1.9 dS/m
CROP
Citrus
Potato
Eggplant
Tomato
Okra
Squash
Malok
Beans
Stone fruit
Pepper
Cauliflower / Cabbage
Lettuce
Maize
LEGEND
YIELD POTENTIAL
90 - 100 %
80 - 90 %
70 - 80 %
< 70 %
No Salt tolerance Data
0.00
10.00
20.00
30.00
40.00
50.00
60.00
% OF IRRIGATED AREA

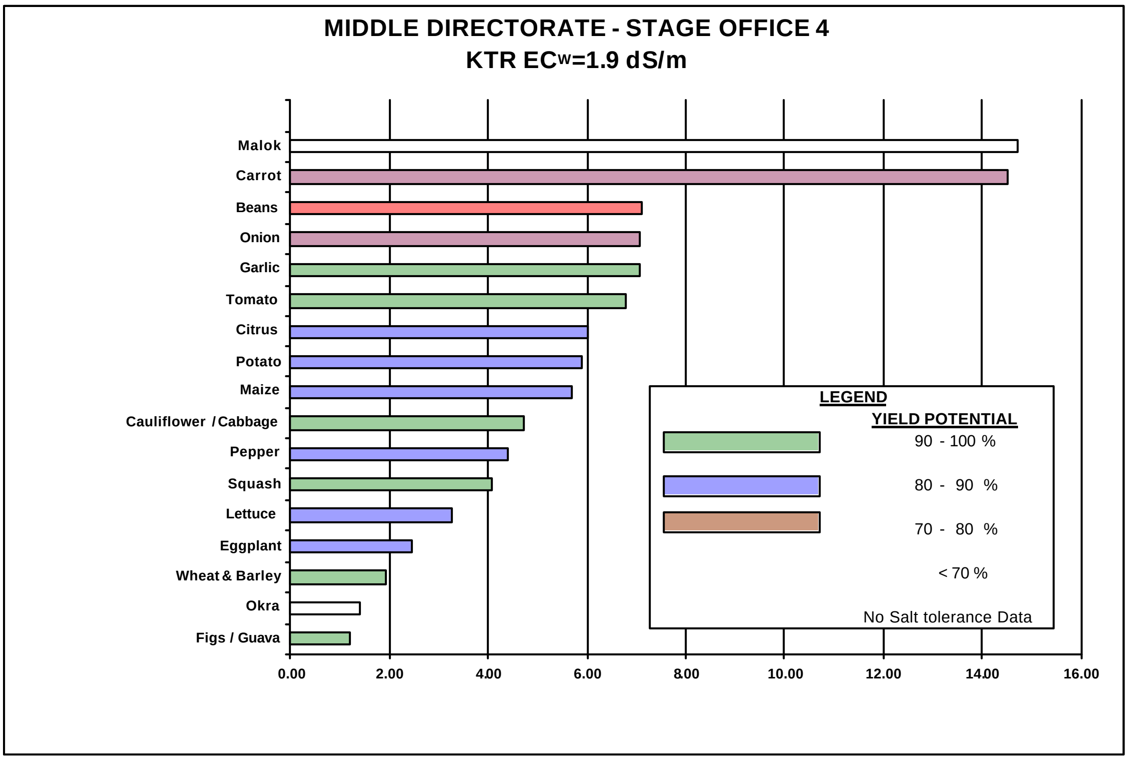

NORTH DIRECTORATE - STAGE OFFICE 7
KTR ECW=2.4 dS/m
CROP
Citrus
Tomato
Wheat & Barley
Malok
Banana
Squash
Peas
Alfalfa / Berseem
Figs / Guava
Eggplant
Beans
Cauliflower / Cabbage
Nurseries
Okra
Lettuce
Potato
Stone fruit
Olives
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
% OF IRRIGATED AREA

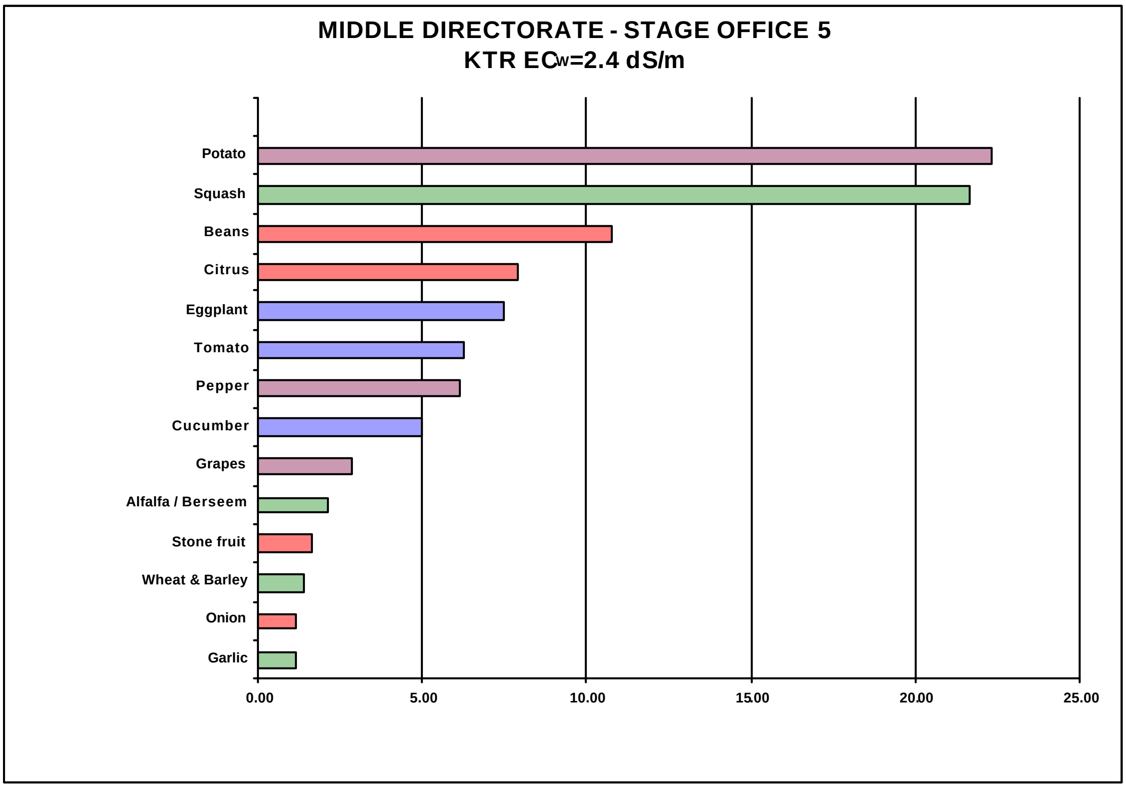

NORTH DIRECTORATE - STAGE OFFICE 7
KTR ECW=1.9 dS/m
CROP
Citrus
Tomato
Wheat & Barley
Malok
Banana
Squash
Peas
Alfalfa / Berseem
Figs / Guava
Eggplant
Beans
Cauliflower / Cabbage
Nurseries
Okra
Lettuce
Potato
Stone fruit
Olives
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
% OF IRRIGATED AREA

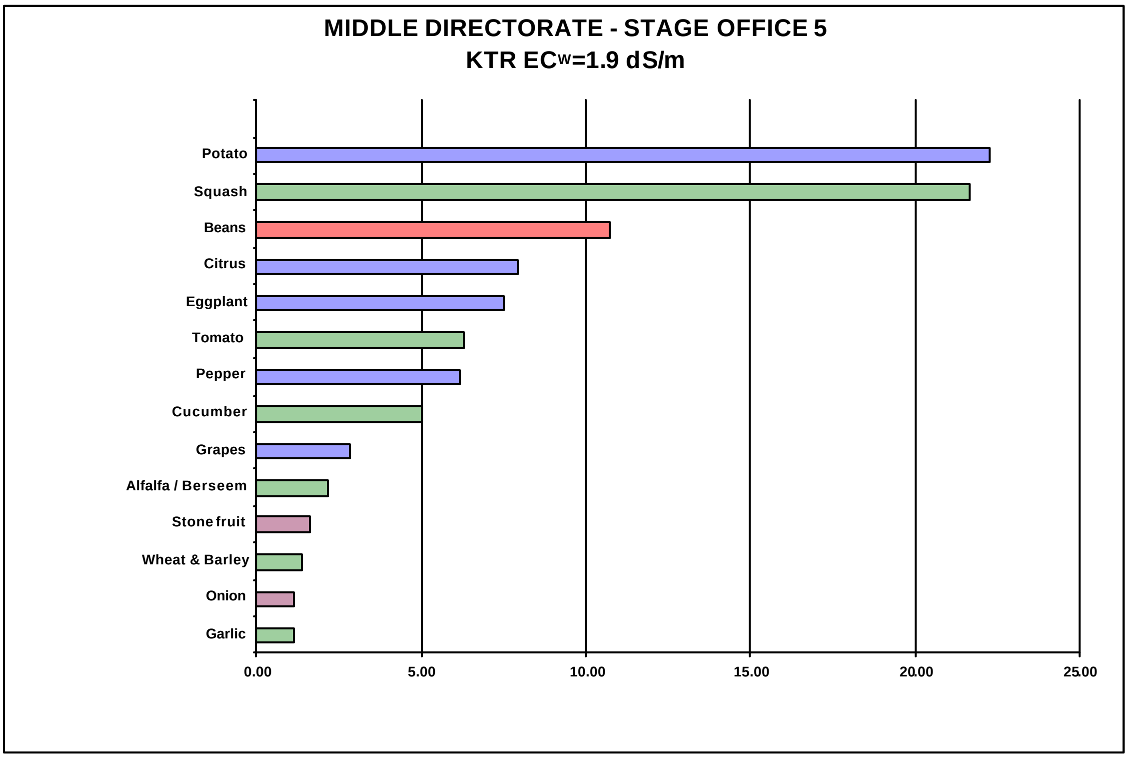

MIDDLE DIRECTORATE - STAGE OFFICE 3
KTR ECw=2.4 dS/m
Citrus
Tomato
Potato
Cucumber
Squash
Wheat & Barley
Pepper
Beans
Lettuce
Eggplant
Onion
Garlic
0.000
2.000
4.000
6.000
8.000
10.000
12.000
14.000
16.000
18.000
20.000

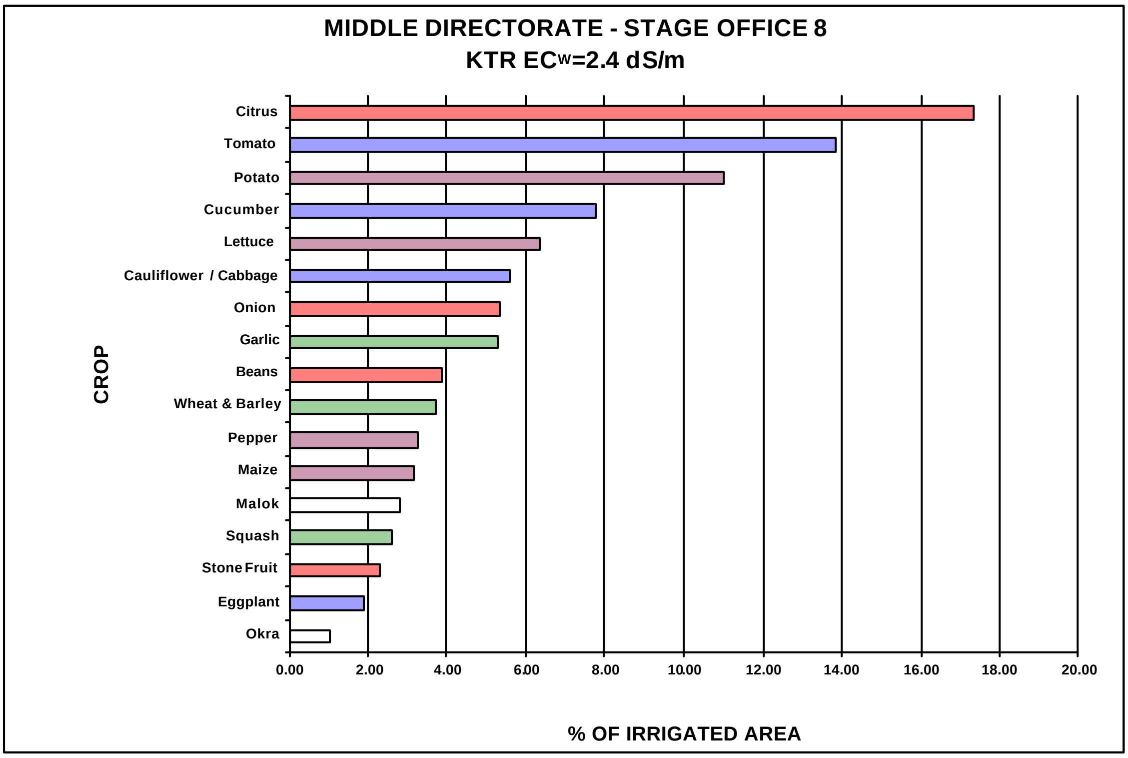

MIDDLE DIRECTORATE - STAGE OFFICE 3
KTR ECw=1.9 dS/m
Citrus
Tomato
Potato
Cucumber
Squash
Wheat & Barley
Pepper
Beans
Lettuce
Eggplant
Onion
Garlic
0.000
2.000
4.000
6.000
8.000
10.000
12.000
14.000
16.000
18.000
20.000

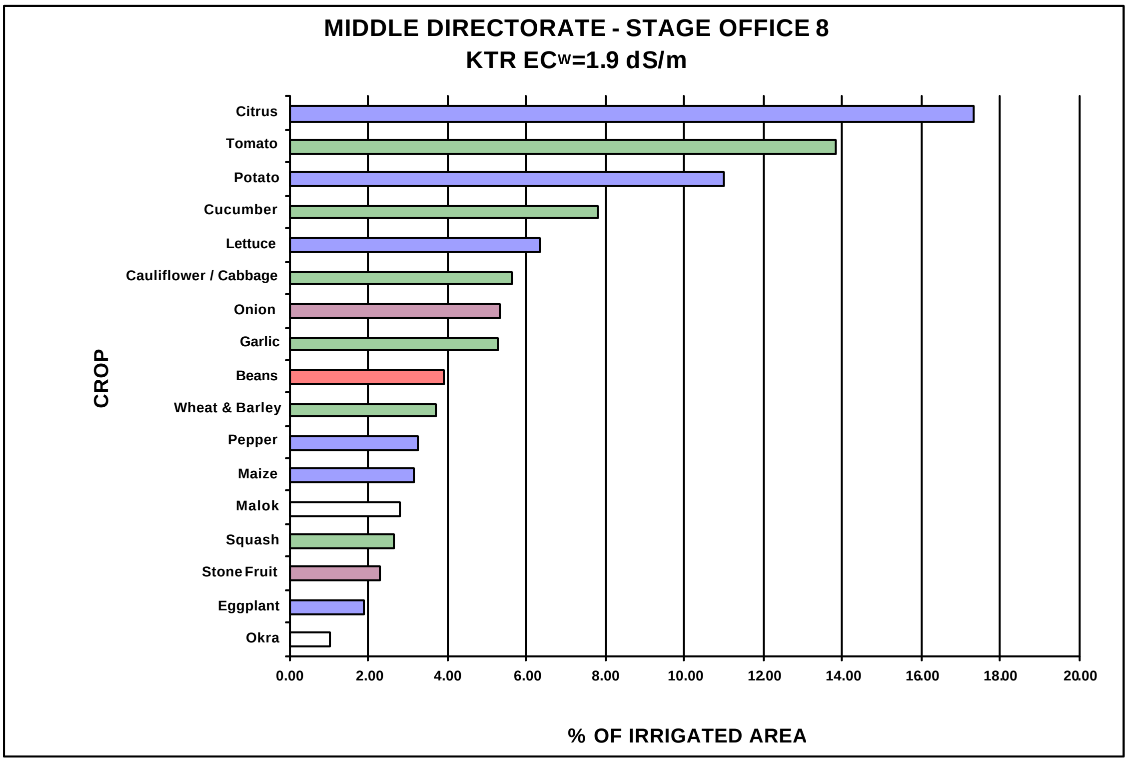

MIDDLE DIRECTORATE - STAGE OFFICE 4
KTR ECw=2.4 dS/m
Malok
Carrot
Beans
Onion
Garlic
Tomato
Citrus
Potato
Maize
Cauliflower / Cabbage
Pepper
Squash
Lettuce
Eggplant
Wheat & Barley
Okra
Figs / Guava
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00

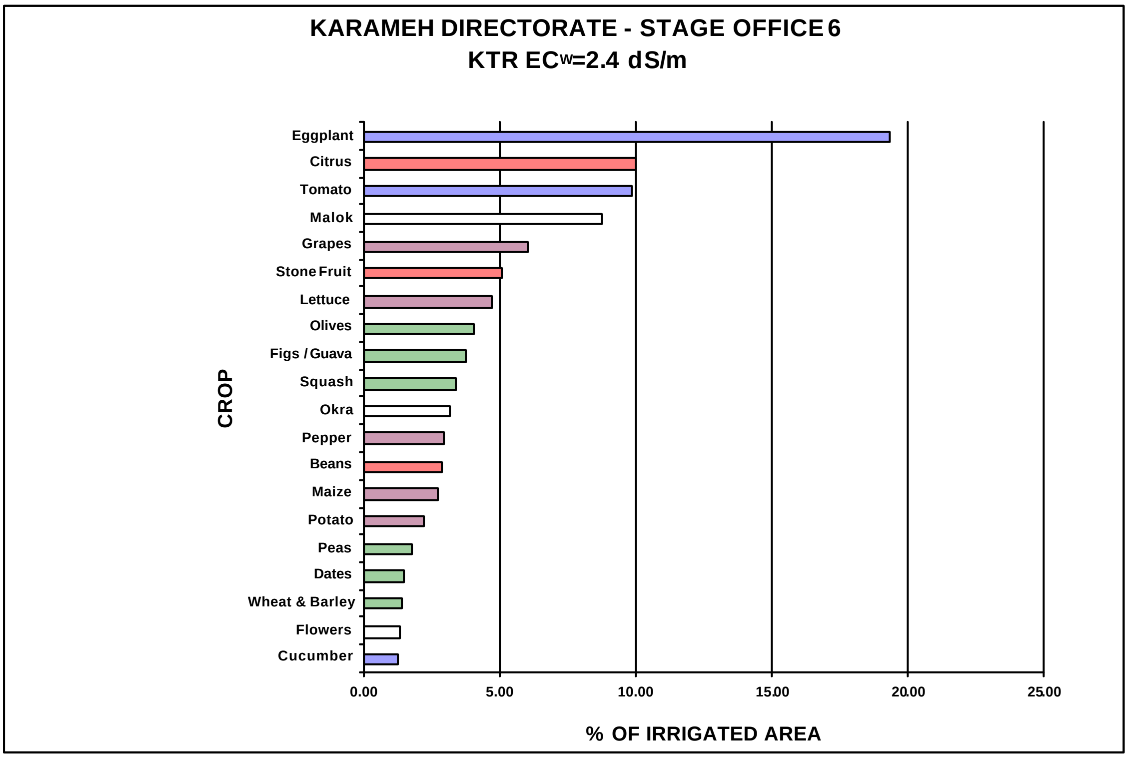

MIDDLE DIRECTORATE - STAGE OFFICE 4
KTR ECw=1.9 dS/m
Malok
Carrot
Beans
Onion
Garlic
Tomato
Citrus
Potato
Maize
Cauliflower / Cabbage
Pepper
Squash
Lettuce
Eggplant
Wheat & Barley
Okra
Figs / Guava
LEGEND
YIELD POTENTIAL
90 - 100 %
80 - 90 %
70 - 80 %
< 70 %
No Salt tolerance Data
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00

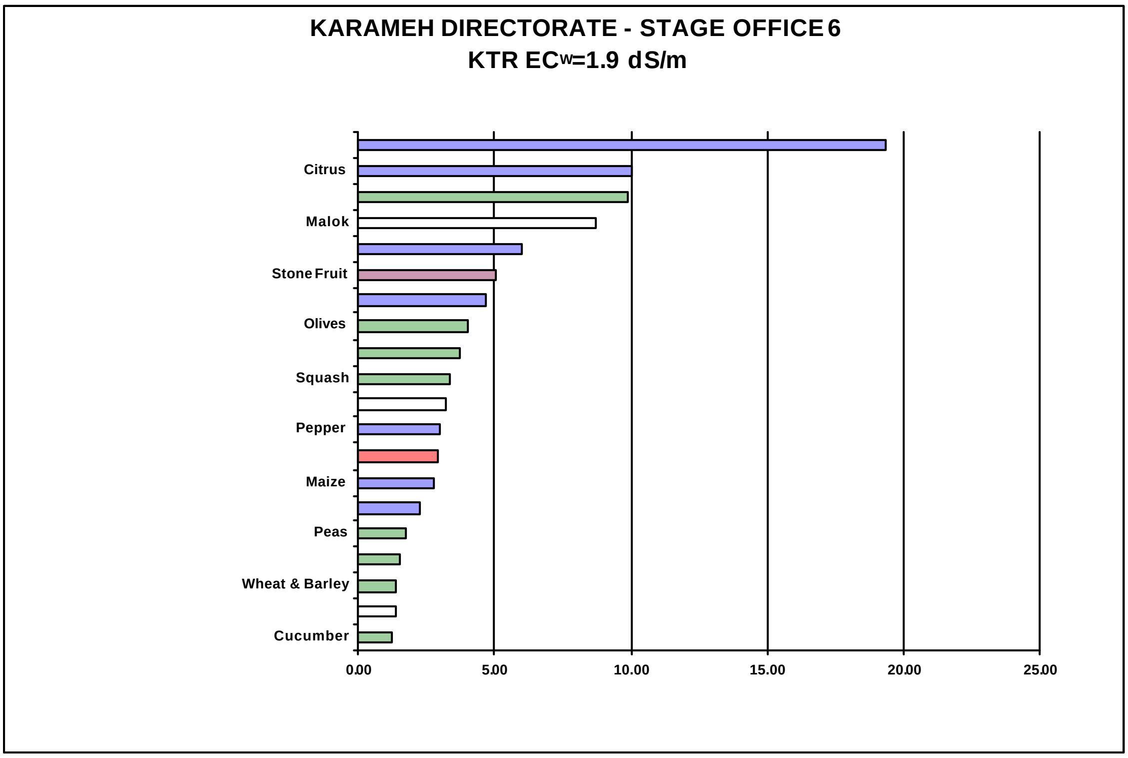

MIDDLE DIRECTORATE - STAGE OFFICE 5
KTR ECw=2.4 dS/m
Potato
Squash
Beans
Citrus
Eggplant
Tomato
Pepper
Cucumber
Grapes
Alfalfa / Berseem
Stone fruit
Wheat & Barley
Onion
Garlic
0.00
5.00
10.00
15.00
20.00
25.00

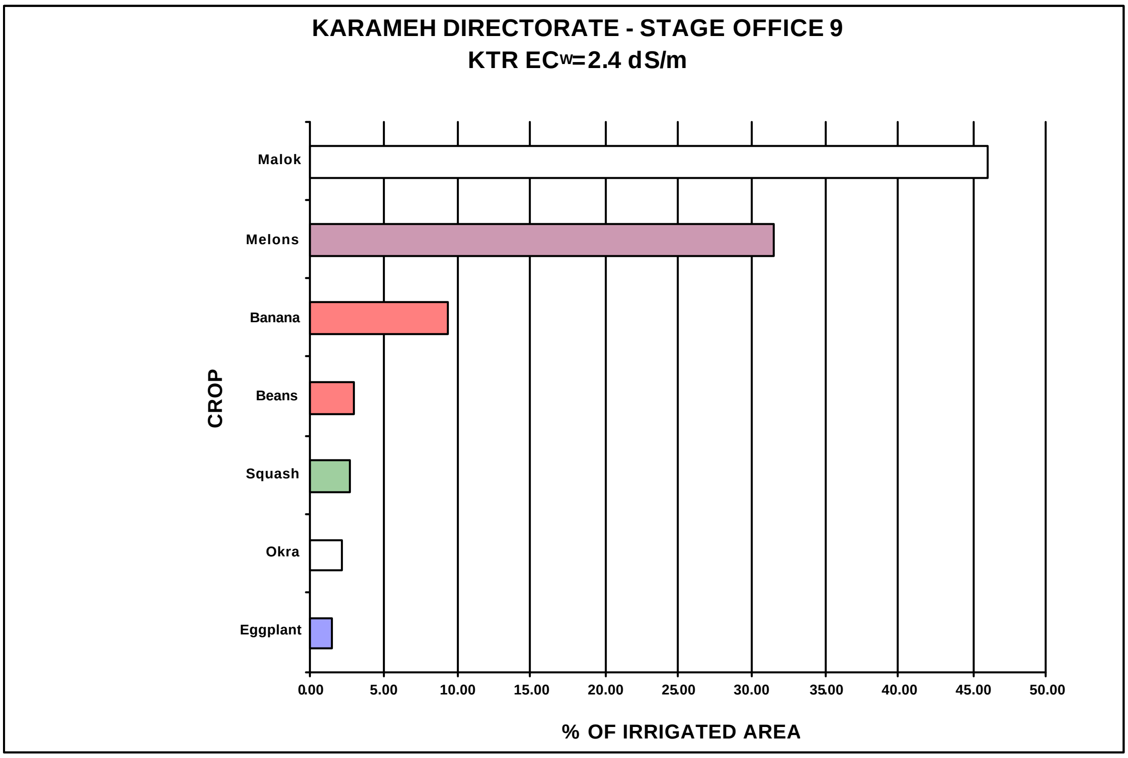

MIDDLE DIRECTORATE - STAGE OFFICE 5
KTR ECw=1.9 dS/m
Potato
Squash
Beans
Citrus
Eggplant
Tomato
Pepper
Cucumber
Grapes
Alfalfa / Berseem
Stone fruit
Wheat & Barley
Onion
Garlic
0.00
5.00
10.00
15.00
20.00
25.00

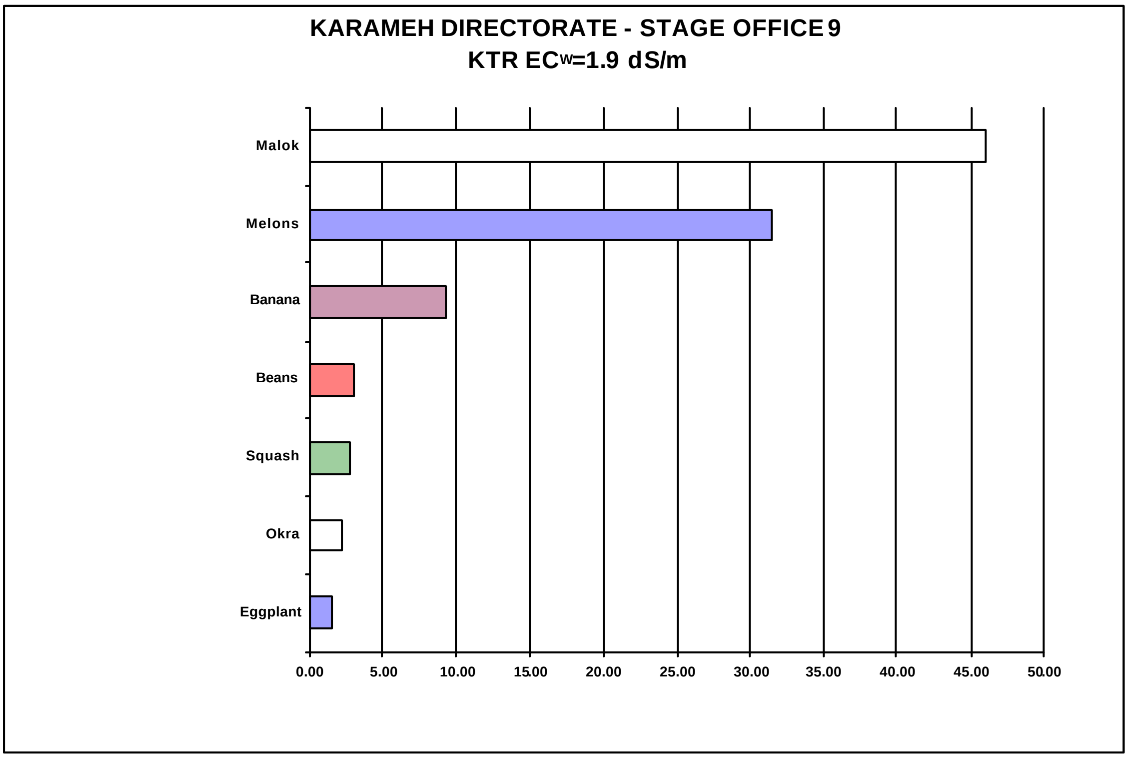

MIDDLE DIRECTORATE - STAGE OFFICE 8
KTR ECw=2.4 dS/m
CROP
Citrus
Tomato
Potato
Cucumber
Lettuce
Cauliflower / Cabbage
Onion
Garlic
Beans
Wheat & Barley
Pepper
Maize
Malok
Squash
Stone Fruit
Eggplant
Okra
0.00 2.00 4.00 6.00 8.00 10.00 12.00 14.00 16.00 18.00 20.00
% OF IRRIGATED AREA

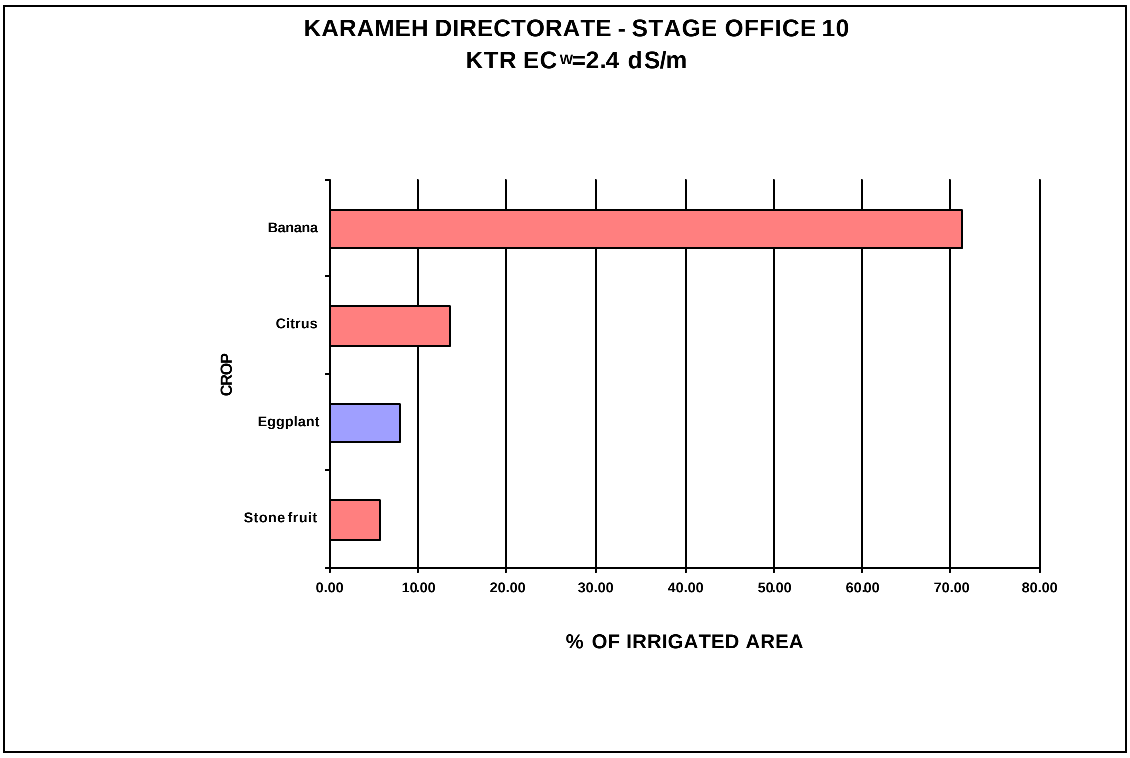

MIDDLE DIRECTORATE - STAGE OFFICE 8
KTR ECw=1.9 dS/m
CROP
Citrus
Tomato
Potato
Cucumber
Lettuce
Cauliflower / Cabbage
Onion
Garlic
Beans
Wheat & Barley
Pepper
Maize
Malok
Squash
Stone Fruit
Eggplant
Okra
0.00 2.00 4.00 6.00 8.00 10.00 12.00 14.00 16.00 18.00 20.00
% OF IRRIGATED AREA

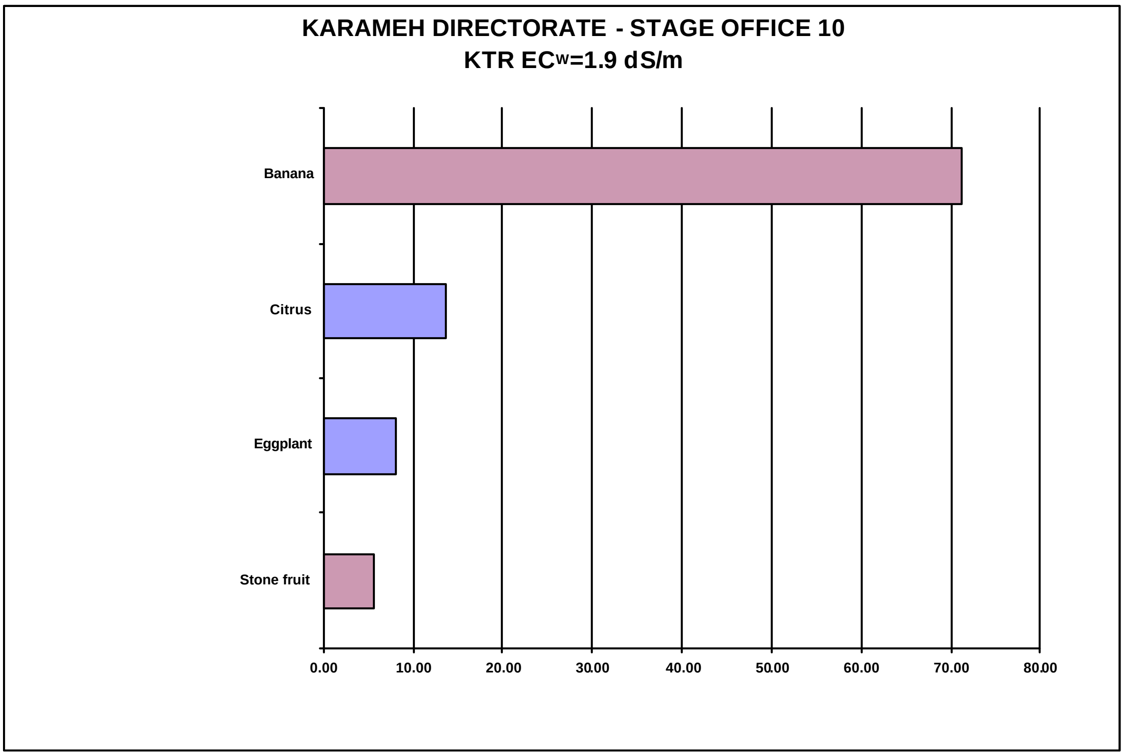

KARAMEH DIRECTORATE - STAGE OFFICE 6
KTR ECw=2.4 dS/m
CROP
Eggplant
Citrus
Tomato
Malok
Grapes
Stone Fruit
Lettuce
Olives
Figs / Guava
Squash
Okra
Pepper
Beans
Maize
Potato
Peas
Dates
Wheat & Barley
Flowers
Cucumber
0.00
5.00
10.00
15.00
20.00
25.00
% OF IRRIGATED AREA


KARAMEH DIRECTORATE - STAGE OFFICE 6
KTR ECw=1.9 dS/m
Citrus
Malok
Stone Fruit
Olives
Squash
Pepper
Maize
Peas
Wheat & Barley
Cucumber
0.00
5.00
10.00
15.00
20.00
25.00


KARAMEH DIRECTORATE - STAGE OFFICE 9
KTR ECw=2.4 dS/m
CROP
Malok
Melons
Banana
Beans
Squash
Okra
Eggplant
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
% OF IRRIGATED AREA


KARAMEH DIRECTORATE - STAGE OFFICE 9
KTR ECw=1.9 dS/m
Malok
Melons
Banana
Beans
Squash
Okra
Eggplant
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00


KARAMEH DIRECTORATE - STAGE OFFICE 10
KTR ECw=2.4 dS/m
CROP
Banana
Citrus
Eggplant
Stone fruit
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
% OF IRRIGATED AREA


KARAMEH DIRECTORATE - STAGE OFFICE 10
KTR ECw=1.9 dS/m
Banana
Citrus
Eggplant
Stone fruit
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00